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Analysis of socio-economic impacts of sustainable sugarcane–ethanol production by means of inter-regional Input–Output analysis: Demonstrated for Northeast Brazil

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ABSTRACT

This study assesses the socio-economic impacts in terms of value added, imports and employment of sugarcane-derived bioethanol production in Northeast (NE) Brazil. An extended inter-regional Input–Output (IO) model has been developed and is used to analyse three scenarios, all projected for 2020: a business-as-usual scenario (BaU) which projects current practices, and two scenarios that consider more efficient agricultural practices and processing efficiency (scenario A) and in addition an expansion of the sector into new areas (scenario B). By 2020 in all scenarios, value added and imports increase compared to the current situation. The value added by the sugarcane–ethanol sector in the NE region is 2.8 billion US$ in the BaU scenario, almost 4 billion US$ in scenario A, and 9.4 billion US$ in scenario B. The imports in the region will grow with 4% (BaU scenario), 38% (scenario A) and 262% (scenario B). This study shows that the large reduction of employment (114,000 jobs) due to the replacement of manual harvesting by mechanical harvesting can be offset by additional production and indirect effects. The total employment in the region by 2020 grows with 10% in scenario A (around 12,500 jobs) and 126% in scenario B (around 160,000 jobs). The indirect effects of sugarcane production in the NE are large in the rest of Brazil due to the import of inputs from these regions. The use of an extended inter-regional IO model can quantify direct and indirect socio-economic effects at regional level and can provide insight in the linkages between regions. The application of the model to NE Brazil has demonstrated significant positive socio-economic impacts that can be achieved when developing and expanding the sugarcane–ethanol sector in the region under the conditions studied here, not only for the NE region itself but also for the economy of the rest of Brazil.

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1. Introduction

Among first generation biofuels, sugarcane derived ethanol produced in Brazil is one of the most competitive fuels and is, together with corn based ethanol from the US, one of the two world leading sources of biofuel, covering 87% of global production [1,2]. The production of fuel ethanol has increased enormously over the last decade, from 340 PJ in 2000 to 1540 PJ in 2009, and to over 1780 PJ in 2011 [2,4]. Sugarcane–ethanol also has a favourable GHG balance, compared to other crops such as sugar beet, wheat straw and corn [1,5]. Brazil is a large producer thanks to amongst other reasons, the supportive governmental policies [6,7]. Brazil also has a favourable tropical climate with sufficient rainfall and high temperatures. Brazil produced 506 PJ ethanol in 2009, and around 540 PJ in 2011,which is about one-third of the total global fuel ethanol production. The majority ($>80\%$) is used within Brazil, export is limited and fluctuates with the price of sugar [2]. The majority of sugarcane and ethanol production in Brazil, is located in the Centre-South (CS) of Brazil. In the Northeast (NE) of Brazil, on the other hand, mostly sugar is produced and only 7% of the total national ethanol production [8].

In order to facilitate manual harvesting, sugarcane fields need to be set on fire to remove dry leaves and repel poisonous animals. There are numerous negative impacts associated with burning sugarcane such as soil degradation and increased air pollution. Therefore, a Brazilian regulation that came up in 2002 (11241/02), aimed to gradually eliminate this practice by limiting manual harvesting and replacing it with mechanised harvesting. Mechanised harvesting brings along a number of benefits such as soil improvement; leaves of the sugarcane are left on the ground, instead of being burned, acting as fertilizers and maintaining the humidity of the soil. Furthermore, it is more cost effective. On the other hand, mechanised harvesting negatively impacts employment, an estimated 114,000 sugarcane cutters are expected to lose their jobs in the CS region between 2006 and 2020 [9]. Most of these workers are immigrants from the NE.

There are large differences between the production systems of sugarcane–ethanol of the CS and the NE regions. While the production in the CS is well developed and continuously improving in terms of efficiency and sustainability, the productivity achieved in the NE is lower due to climate, terrain characteristics and lower technological levels. Although the sector in the NE has some benefits compared to the sector in the CS such as good storage and loading infrastructure in the terminals, lower transport costs, higher incentives for sugar exports, there is still room for improvement in the production sector of the NE [10]. In the CS region, 50% of the sugarcane is mechanically harvested while in the NE manual harvesting still predominates in 95% of the areas. This is due to the uneven topography of the NE where 50% of the sugarcane production areas has slopes above 12%. Areas in the NE that have slopes lower than 12%, need to comply with the law whereby mechanisation of harvesting is required by 2018. In the remaining areas, mechanised harvesting will theoretically be implemented by 2031. However, due to the lack of operational harvesting machines for steep slopes, the deadline to comply with the regulation in the areas with slopes steeper than 12%, is still not clear. The NE region stands out as the poorest region of the country with a high number of people living under the poverty line and a high rate of illiteracy. There is a need to develop the NE region to promote economic growth and to create job opportunities. Gaining more insight into

the possibilities and challenges of the biofuel sector in the NE is essential to become as sustainable and competitive as the CS. Although international biofuels certification systems are present, socio-economic concerns around bioenergy production still exist in the NE region [12–18].

This research aims to demonstrate a methodology that quantifies key socio-economic impacts of the production of bioethanol in the NE, in particular the impact on GDP, imports and employment. The study uses Input–Output (IO) analysis as a tool to quantify the direct and indirect impacts of the new bioenergy activity. This methodology has previously been applied in several studies to analyse the impact of producing biofuel on amongst others GDP and employment; [19–22]. Input–Output analysis can be combined with bottom up field and process data to analyse e.g., direct and indirect employment effects of biofuel, which has been done for example for biodiesel and bioethanol production in Thailand [23]. Because the sugarcane–ethanol sector uses different types of technologies, an IO model with mixed technologies was used. This methodology was first proposed by Cunha [24] and it is described by Cunha and Scaramucci [25]. Using bottom up technology information in combination with an Input–Output analysis has also been performed by Neuwahl et al. [26]; they modelled employment impacts due to biofuel policies in the European Union. However, the studies that were mentioned look at country level (Brazil, Thailand), or even larger (EU-market). It is therefore not possible to obtain details on a regional level or even on different areas within one region.

Within the conventional IO analysis, an inter-regional approach is employed to be able to study the impacts in different regions. By using a bottom-up approach, scenarios with projections for 2020 have been drawn, that include not only traditional producing areas of the NE but also potential areas in which sugarcane production in the NE can be expanded. IO analysis allows assessing the economic linkages within the different provinces of the NE as well as studying the dependences of the studied region on the other Brazilian regions. Furthermore, it is possible to assess the different regional contributions to the total impact generated on the national economy.

In Section 2, the methodology is explained, which is followed by an overview of the input data that are used to develop the IO model for this study (Section 3). The results are presented in Section 4, Section 5 contains the discussion and recommendations and Section 6 the conclusions. Furthermore, the appendices provide additional information on the sugarcane and ethanol sector in the NE (Appendix A), additional input for the scenario description (Appendix B), details on the construction of the extended inter-regional IO model (Appendix C), input data for the IO analysis (Appendix D) and detailed output results (Appendix E).

2. Methodology

2.1. IO analysis

Input–Output (IO) analysis is widely applied to conduct national economic analyses and structural research, and is also used to assess macro-economic impacts of bioenergy production [27,28,30]. The methodology allows for evaluating the impacts of new economic activities on a regional or national economy, by using IO tables. IO tables represent annual monetary flows of goods and services among different sectors in the economy. In this study, IO analysis is used to determine the impacts of sustainable sugarcane–ethanol production in the NE of Brazil on *GDP*, *employment* and *imports*. A scenario approach has been deployed that includes different levels of yield, processing efficiencies and additional land for sugarcane cultivation (expansion land).

The direct value added or impact on GDP (V_{dir}), imports (M_{dir}) and employment (E_{dir}) are estimated from the correspondent impacts over the activities that are affected directly by the sugarcane–ethanol sector, while the indirect impacts relate to the indirectly affected activities, so that,

$$\Delta V_{ind} = w_{nr}\Delta X \tag{1}$$

$$\Delta M_{ind} = m_{nr}\Delta X \tag{2}$$

$$\Delta E_{ind} = e_{nr}\Delta X \tag{3}$$

where w_{nr}, m_{nr} and e_{nr} are the normalised vectors of value added, imports and employment with the elements $w_{nr,i}=w_i/x_i$, $m_{nr,i}=m_i/x_i$ and $e_{nr,i}=e_i/x_i$ respectively. Furthermore, X represents the total output, i represents the sector and x represents the output of each sector.

2.2. Extended inter-regional IO model

IO models are most commonly constructed to analyse socio-economic impacts of an activity on a country level. To be able to study a specific region and the relationship of the impacts among regions, an inter-regional model can be constructed, see Isard [31] and Liang et al. [32]. The inter-regional model used in this research is derived from the single-nation model of Brazil by “disconnecting” the economy of the NE region from the rest of the Brazilian economy. However for the purpose of this study, two separate areas are differentiated within NE Brazil (traditional areas and expansion areas). Therefore, a total of three regions are distinguished (i.e., traditional areas, expansion areas and the rest of Brazil), making it an extended inter-regional IO model.

The regional disaggregation used in this study cover the following three areas: (i) *Traditional areas* of the NE; including the states of Alagoas, Pernambuco and Paraíba in which currently more than 80% of the total production of sugarcane in the NE takes place; (ii) *Expansion areas* of the NE; including all other smaller sugarcane producing states of the NE (Bahia, Maranhão, Piauí, Sergipe, Ceará and Rio Grande do Norte). In some of these states an expansion of sugarcane can take place as outlined in the Brazilian Sugarcane Zoning exercise [33]; (iii) *Rest of Brazil*; including all other Brazilian states (see Fig. 1).

The IO table used for this research was constructed by the Institute of Geography and Statistics of Brazil, and is based on the data in the tables of the Brazilian National Accounting System of 2004 [34]. More recent tables are not yet available, see discussion section. In order to build an IO table for the NE region, additional information was used from the Ministry of Work and from the Ministry of Development, Industry and External Commerce [35–37]. The employment figures and wages for each sector were based on data from the Institute of Geography and Statistics of Brazil [38]. The original 64 sectors were aggregated to 34 sectors, including separate sectors for sugarcane, ethanol and sugar, see Appendix C3.

2.3. Industry-based and commodity-based approaches

In order to introduce the technologies that are considered in the three scenarios of this analysis, the initial IO table was modified. One of the modifications is related to the introduction of technology-differentiated sectors; that is, different sectors applying different technologies to produce the same good [24,25]. For example, sugarcane can be manually or mechanically harvested, sugarcane can be irrigated or not, and ethanol can be produced either in a distillery or in a mixed sugarmill.



Fig. 1. Regional disaggregation that is used in the extended inter-regional IO model of Brazil.

This methodology permits accounting for different production systems to produce the same commodity. An example of this type of approach can be found in Appendix C1. In the extended IO model, *the industry-based technology* is applied for the technologies that only produce one commodity (e.g., sugarcane production, the ethanol produced in a distillery and the sugar produced in a sugar factory).

However, the industry-based technology approach is not the best if the production of one commodity in one sector can occur simultaneously with the generation of other commodities at the same proportion. For instance, in a mixed sugarmill, the production of ethanol occurs at the same time as sugar production and the production of electricity from bagasse. Therefore, the approach that takes this into account, called the *commodity-based technology*, is applied as well. See Appendix C2 for an example of this approach.

2.4. Technology differentiated sectors

There are 15 technologies included in the extended IO model, Table 5 at the end of this section lists these technologies together with the scenarios in which they are included. By including the 15 new technologies with the 34 sectors for the three different studied regions, the IO matrix used in this study is obtained. See Appendix C4 which shows the structure of the model.

To introduce the new technologies that include changes in agriculture in the extended IO model, it is necessary to calculate the corresponding technical coefficients of production for the 34 sectors that are present in the IO table. The technical coefficients of production represent the ratio that gives the monetary value used in each sector per one monetary value worth of each output. These coefficients are calculated using production costs, provided in the Input Data Section. By dividing each individual costs by the total sugarcane production costs, the technical coefficients for each technology studied are calculated (see Appendix D).

IO analysis commonly uses the final demand (Y) as exogenous variable and the production output (X) as endogenous component. This means that changes in the final demand are made outside the model and the IO model quantifies the effects of these changes on the economy's gross outputs. In some cases however, a mix of

Table 1
Exogenous variables considered in the extended inter-regional IO model for each region.

Studied regions	Exogenous variables	Number of exogenous variables
Traditional areas NE	X ethanol X sugar 32 Y's	34
Expansion areas NE	X ethanol X sugar 32 Y's	34
Rest of Brazil	Y's	34
Total		102

exogenous/endogenous components is more appropriate. This is the case in this study because the final demand for sugarcane–ethanol is a result of a more sustainable and expanded sugarcane production. All final demand variables corresponding to each of the 34 sectors were considered exogenous except the final demand for ethanol ($Y_{ethanol}$) and sugar (Y_{sugar}), shown in Table 1. These two final demands were considered endogenous so the production output of ethanol ($X_{ethanol}$) and sugar (X_{sugar}), were exogenous components in this model.

The 15 newly introduced technologies result in 15 equations from which 6 equations are related to sugarcane production, 6 to ethanol production, 2 for sugar production and 1 for livestock production. Furthermore, the additional 34 sectors of the initial IO table lead to 34 basic equations of the IO model ($AX+Y=X$). Combining the 15 equations (for each of the two NE regions) with the 34 sectors of the IO table (for each of the three areas studied) gives a total of 132 independent equations, see Table 2.

These 132 activities will lead to

- 132 output variables in the IO model (X_1–X_{132})
- 102 final demand variables (Y_1–Y_{102})

Thus, the extended IO model uses a total of 234 variables, of which 132 are endogenous to the system and 102 are exogenous variables. All cost data and assumptions that are used to include the new technologies in the IO model are provided in Section 3 and Appendix D.

The initial IO table gives information about the amount of employment generated as well as the average wages paid to the employees. The amount of employment per unit of production value is calculated using the following formula:

$$\text{Employment per production value (jobs/US\$)} = \frac{\textit{technical coefficient labour}}{12\ (\textit{months})\ \times \textit{wage}\ \left(\frac{US\$}{month}\right)} \tag{4}$$

The technical coefficients of labour for each technology are provided in Appendix D together with wages per sector (sugarcane production, mixed sugarmill, distillery and sugar factory).

2.5. Electricity production by sugarmills

Bagasse is a byproduct of sugar and ethanol production and can be used to generate electricity. In the results section the total amount of electricity that is generated at sugarmills is calculated by subtracting the value of the total electricity consumption of all sugarmills from the value of the total additional electricity produced by the mills (both values are provided by the input/output tables). This value is then divided by the producer's electricity price (28.8 $/MWh), which is assumed to stay constant over time.

Table 2
Number of equations used in the extended inter-regional IO model to solve the system.

Technologies	Per region	Total (all regions)
Sugarcane	6	12
Ethanol	6	12
Sugar	2	4
Livestock	1	2
$AX+Y=X$	34	102
Total equations		132

Table 3
Interviewees of 6 different stakeholder groups.

Type of group interviewed	Name (province)	Number of people interviewed
Sugarmills	Caeté (Alagoas)	4
	Coruripe (Alagoas)	6
	Pindorama (Alagoas)	4
Association of sugarmills	Sindaçucar (Pernambuco)	1
Outgrowers unions	ASPLANA (Alagoas)	1
	Outgrowers association (Pernambuco)	1
Experts and research centers	STAB (Alagoas)	1
	STAB (Pernambuco)	1
	RIDESA (Pernambuco)	2
	CTBE	5
	EMBRAPA	3
Worker's unions	Union of rural workers of Coruripe (Alagoas)	3
NGO's	Repórter (São Paulo)	2
	Solidaridad (São Paulo)	1

2.6. Sensitivity analysis

A sensitivity analysis is included in which the sugarcane yield and the amount of land on which sugarcane cultivation can be expanded are varied.

2.7. Data collection

Next to extensive literature reviews, interviews with a total of 35 people were carried out in Brazil, see Table 3. Data was collected during fieldwork (January–May 2011) in NE (Alagoas and Pernambuco states) and CS of Brazil (São Paulo state). In the NE region, three different sugarmills were visited. Due to the large amount of sugarcane outgrowers in the region, interviews were also carried out with the presidents of the outgrowers unions of Alagoas and Pernambuco. Another interview was performed with the president of Sindaçucar which is an association of 19 sugarmills of the state of Pernambuco and a central institution in the sugarcane–ethanol sector of the NE region. Numerous specialists in the sugarcane–ethanol sector who work in R&D centres and other technical institutions specialized in the sugarcane–ethanol field were interviewed. Finally, in order to gather information related to employment two non-governmental organisations and two unions of rural workers were interviewed.

2.8. Scenarios for sustainable sugarcane–ethanol production in NE Brazil

The specific conditions found in the NE allowed for identifying potential improvements that can take place to achieve a more efficient and sustainable production and for making sugarcane expansion possible. This information has been used to define three different scenarios for 2020. The system boundary in the scenarios covers production and processing of sugarcane. The Business-as-Usual (BaU) scenario projects current management and performance of the production chain without significant changes. Two alternative scenarios, scenario A and B, consider the introduction of more advanced and efficient technologies that can increase agricultural and industrial productivities. Scenario B furthermore includes expansion of sugarcane production on additional land. Potential areas with high and medium productivity have been identified using the Sugarcane Zoning of the NE of Brazil [33]. Areas have been excluded where crops are being cultivated and only areas used for extensive livestock (with 1–2 heads/ha) are considered. Expected population growth was taken into account to determine the amount of pasture land needed to satisfy food consumption. The suitable areas sum up to 1.2 million ha and they are located in the provinces of Bahia, Maranhão and Piauí. The current extensive livestock production system is considered to become slightly more efficient (passing from 2 to 3 heads/ha) which frees up enough land to cultivate sugarcane in the new expansion areas. The main technological changes that are included in the scenarios for the NE region are: implementation of irrigation, mechanical harvest of sugarcane and use of improved sugarcane species. The three projected scenarios are compared with the situation in 2010 (the reference scenario) to perform the IO analysis. The agricultural and industrial variables that define the different scenarios are summarised in Table 4. Table 5 lists the 15 new technologies with the respective scenarios in which they are used. More detailed information about the structure of the sector and sugarcane, ethanol and electricity production in NE Brazil, can be found in Appendix A. In Appendix B more background information is provided about the compilation of the scenarios.

3. Results

The IO analysis gives the change in total output (see the detailed table in Appendix E). This total output is multiplied by the GDP, imports and employment coefficients of the IO table to calculate the total impact of each of these variables. In Fig. 2 and Table 6, the results for the NE region and Brazil for value added, imports and employment, are shown for the three scenarios.

The socio-economic impacts of the sugarcane–ethanol sector in the NE region in absolute figures per region and for Brazil, are presented in Table 6.

Scenario B shows the largest impact on GDP, imports and employment. The results of scenario B also show that if an economic activity takes place in the NE expansion areas, different growth rates in value added, imports and employment are found in the other two studied areas. Here, the economy of the rest of Brazil is more favoured than the economy of the traditional areas of the NE because the CS region of Brazil produces a significant amount of the items used by the sugarcane sector in the NE region. In contrast, the traditional region (formed by the states of Alagoas, Pernambuco and Paraíba) has hardly any industrial activity. In the NE region most of the industry is concentrated in the expansion areas. Bahia has an important petrochemical complex (Camaçari) and a large car producing plant and the state of Ceará has metallurgic and cement sectors. This industrial activity supplies a significant part of the required items used by the sugarcane–ethanol sector in the whole NE region such as petrol and refined petroleum products and fertilizers and agrochemicals.

The breakdown of impacts by sector shows that the composition by impact type (direct and indirect) differs for each sector and per region, see Appendix E. All sectors that provide inputs that are directly used for the production of ethanol and sugar in the NE are identified as direct impacts. Note that the impacts on the ethanol and the sugar sector in the two North-eastern regions are 100% direct (and 100% indirect in the rest of Brazilian regions) because

Table 4
Summary of parameters that define the scenarios used in the IO analysis.

Parameters	Reference 2010	Scenario BaU 2020	Scenario A 2020	Scenario B 2020	Source
Land use (ha)	1,100,600	1,100,600	880,480[a] (areas with slopes < 18%)	880,480[a] (traditional areas) and 1,249,607[b] (expansion areas)	[33,39]
Mechanical harvested areas (for traditional region in NE)	3%	50% (areas with slopes < 12%)	50% (areas with slopes < 12%)	50% (areas with slopes < 12%)	[39,40] [41]
Mechanical harvested areas (for expansion region in NE)	1%	50%	50%	100%	[39,40]
Irrigated areas (ha)	–	–	308,168[c]	745,530[c]	[42]
Sugarcane yield (t/ha)	57[d]	63[e]	97[f]	97[f]	[42]
Ethanol yield (L/t)	80.6[g]	80.6[g]	85.2[h]	85.2[h]	[42]
Sugar yield (kg/t)	135.5[g]	135.5[g]	140.3[h]	140.3[h]	[42]
Electricity use in sugarmill (KWh/t cane)	–	–	75[i] (distillery) and 70 (mix sugarmills)	75[i] (distillery) and 70 (mix sugarmills)	[9] (Industrial program of CTBE, fieldwork)

[a] Calculated by subtracting areas that have slopes higher than 18% (according to experts interviewed during fieldwork these areas represent 30% of the total area in the NE). Currently 7 million ha (out of 65 million ha of arable land) are cultivated with sugarcane in total Brazil [43].

[b] This scenario assumes an expansion of the sector in suitable areas of the NE region, as identified by the Sugarcane Zoning Maps of the NE of Brazil [33]. Only areas used for extensive livestock (with 1–2 heads/ha) are considered and expected population growth was taken into account. The suitable areas sum up to 1.2 million ha and they are located in the provinces of Bahia, Maranhão and Piauí. The current extensive livestock production system is considered to become slightly more efficient (passing from 2 to 3 heads/ha). This means management is almost equal and therefore no change in employment and inputs in the livestock sector are taken into account.

[c] Calculated considering that only medium and large sugarmills, who currently own 35% of total cultivated area, will implement full and/or complementary irrigation.

[d] The average agricultural productivity of sugarcane production in the NE is around 57 t/ha/year which is 26% lower than the national productivity due to its less favourable climate, poorer soils, uneven topography and often, poor management [44]. The structure of the sector is that 30% of the sugarcane production is cultivated by outgrowers (farmers who produce sugarcane and sell to sugarmills) and 70% by sugarmills [42].

[e] Calculated by assuming an annual growth similar to the average of the last 20 years, which is 0.9%, see Fig. B2 in Appendix B [45]. Furthermore, the same structure of the sector is assumed as in the reference scenario, see d.

[f] The same structure of the sector is assumed as in the reference scenario, see [d]. Furthermore, improved sugarcane management is applied (more efficient use of agrochemicals and fertilisers) and improved sugarcane varieties are used. According to agricultural experts interviewed during fieldwork these changes could increase current sugarcane yields by 5.5%/year.

[g] Industrial process efficiency is assumed to be constant, no improvements have taken place in the last 15 years, see Fig. B3 in Appendix B [46].

[h] An improved processing efficiency is assumed, due to modernisation of industrial equipment. An annual growth of 0.56% (for distilleries) and 0.35% (for sugar factories) has been estimated [47]. A typical sugarmill in the NE uses 64% of the sugarcane for sugar production and 36% for ethanol production. Ethanol yield is depicted for a distillery (85.2 L/t), but in a mixed sugarmill this is 30.7 L/t. The sugar yield is depicted for a sugar factory (140.3 kg/t), but in a mixed sugarmill this is 89.8 kg/t.

[i] Surplus electricity is generated by bagasse-based cogeneration. The electricity that is used by the sugarmill for own consumption, is subtracted. 70 kWh/t cane is used in the case of the distillery and 75 kWh/t cane is used for a mixed sugarmill (interviews).

Table 5
Technologies included in the extended inter-regional IO model and the scenarios in which they are considered.

No.	Technology	REF 2010	BaU 2020	A 2020	B 2020
1	Agricultural technology in 2010 with 100% manual harvest	Y			
2	Agricultural technology in 2010 with 100% mechanical harvest	Y			
3	Agricultural technology in 2020 with 100% manual harvest		Y		
4	Agricultural technology in 2020 with 100% mechanical harvest		Y		
5	Agricultural technology in 2020 with 100% manual harvest and higher technological levels (e.g. irrigation, better sugarcane varieties)			Y	Y
6	Agricultural technology in 2020 with 100% mechanical harvest and higher technological levels (e.g. irrigation, better sugarcane varieties)			Y	Y
7	Livestock production intensified (3 heads/ha)				Y
8	Technology in 2010 in the sugarmills producing sugar	Y			
9	Technology in 2010 in the distilleries	Y			
10	Technology in 2010 in the mixed sugarmills	Y			
11	BaU technology in the sugar factories in 2020		Y		
12	BaU technology in the distilleries in 2020		Y		
13	BaU technology in the mixed sugarmills in 2020		Y		
14	Technological improvement for distilleries in 2020 (e.g., surplus electricity produced, more efficient equipment)			Y	Y
15	Technological improvement for mixed sugarmills in 2020 (e.g., surplus electricity produced, more efficient equipment)			Y	Y

the IO model constructed considers sugar and ethanol production in the NE as exogenous variables. The small contribution of indirect impacts in the sugarcane sector is because outputs of the sugarcane sector (seeds) are used as input. The electricity sector also has a big contribution on the direct effects because of the electricity produced in the sugarmills. It is observed that some items used for ethanol and sugar production in the NE region are provided by sectors located outside the NE region, mainly the sector that produces resin, plastic and other chemical products and the steel and metal producing sector.

3.1. Value added

All scenarios add value to GDP compared to the situation in 2010. The technologically advanced scenarios A and B, lead to higher impacts on GDP than the less progressive BaU scenario.

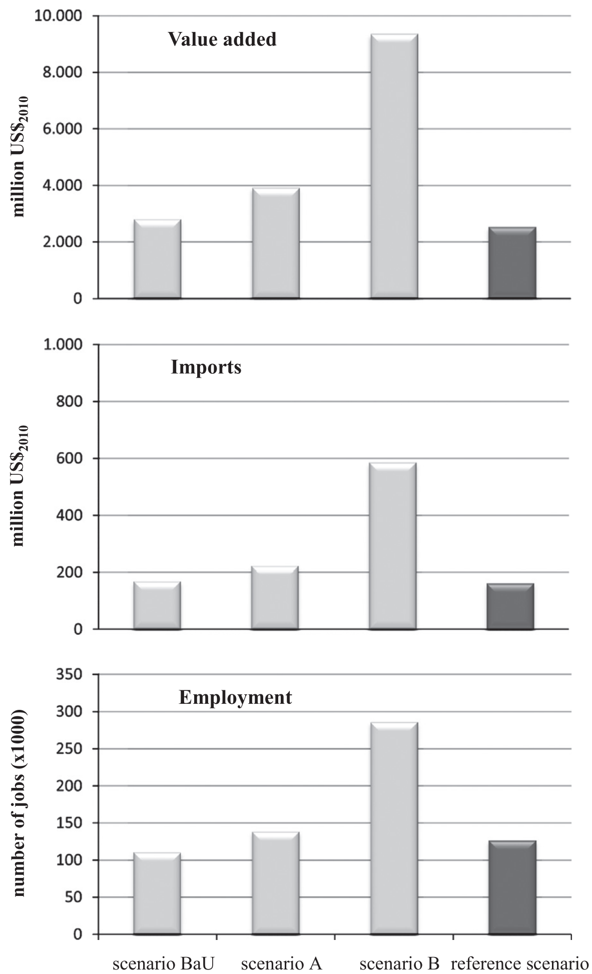


Fig. 2. Total value added, imports and employment in the NE by the NE sugarcane–ethanol sector (traditional and expansion areas) in the scenarios BaU, A and B in 2020, compared with the reference scenario (2010).

Scenario B even leads to an increase of more than 250% compared to the reference scenario. The total GDP of Brazil was around 2200 billion US$$_{2010}$ in 2010, while the total GDP of the NE region of Brazil is 14% of this amount which is just above 207 billion US$$_{2010}$. The relative impact of the scenarios, adds up to 1.3% to the GDP of the NE region in Scenario A and up to 3% in scenario B (and between 0.1% and 0.5% to the total national GDP in 2010 for all three regions combined).

3.2. Imports

In order to comply with the new ethanol and sugar demand studied in each scenario, the need for Brazil to import items increases, especially in scenario B, see Fig. 2.

The Brazilian IO tables [34] show that the main imported items for the sugarcane–ethanol–sugar sectors are: fertilizers, agro-chemicals, machinery and equipment. Other sectors that use significant amounts of imported goods are the sectors: coke and refined petroleum products, fertilizer production and other chemical products, plastic and rubber products, steel and metal products and the machinery sector.

3.3. Employment

As shown in Table 6 a large amount of employment is generated in the NE by scenarios A and B while for the BaU scenario the number of jobs is reduced by 12% compared to the reference scenario. This is caused by the introduction of mechanical harvested sugarcane. When mechanical harvest increases from 3% to 50% (or a change from the reference scenario to the BaU scenario), the total number of jobs in Brazil is reduced by approximately 10%. In scenarios A and B, a reduction of employment by the sugarcane sector due to mechanical harvest also takes place but due to the large amount of jobs created in other economic sectors (e.g., transport) as a result of the additional sugarcane–ethanol–sugar produced, the total number of jobs increases compared to employment in 2010, even by 133% in scenario B.

The impact on the number of sugarcane jobs in the NE region (see Table 7) for scenario A shows that the negative impact of mechanisation of sugarcane harvest on employment is larger than the positive impact related to the productivity gains. In scenario B this effect is only observed in the traditional areas. The additional land that is taken into production in this scenario leads to such job creation that the job reduction effect due to mechanical harvest is reversed.

A simulation was performed in the IO model where the two areas of the NE region are identical in their ethanol and sugar production as well as the technologies used. The results (see figure in Appendix E) show a similar pattern, the direct impacts on GDP are larger in the two areas of the NE compared to the rest of Brazil. While the traditional area of the NE has slightly larger direct impacts than the expansion areas because of the presence of other industrial activities in these areas and the absence of these activities in the traditional areas.

The IO table gives also information about the average wages paid to the employees. The average salaries of employees in each sector differ per sector and per region. In general the salaries paid in most of the sectors of the expansion areas (varying from 142 to 6550 US$/month) are slightly higher than those paid in the traditional areas of the NE region (varying from 58 to 5577 US $/month), see Appendix E for more details. However, the small difference found might be due to the marginal error inherent in the IO model and the data used and thus, the difference should not be concluding. On the other hand it is clear that workers employed in these two regions receive substantial lower salaries than employees in the richer CS region of Brazil. The total average salaries in the CS region are around 75% higher than those paid in the NE region of Brazil. The employees working in the sector of coke and refined petroleum products receive the highest wages (5577–6550 US$/month) while the employees of the livestock sector (126–308 US$/month) and other crop production (58–308 US$/month) receive the lowest wages. The sugarcane sector pays significantly higher salaries (135–362 US$/month) than the average salaries paid when cultivating other crops. The ethanol sector pays modest salaries (255–786 US$/month) compared with other industrial sectors but the salaries are slightly higher than in the sugar production sector.

3.4. Socio-economic impacts of capital investments

The results of the IO analysis do not take the effects of using capital goods to produce the amount of sugar and ethanol that is considered in each scenario into account. So, the effect of the production of capital goods is excluded.

New sugarmills have to be built and new machines and equipment have to be purchased if the additional sugarcane and ethanol is produced and processed. In the 10 years time period that is studied in the scenarios, old machines and equipment will also need to be replaced. The BaU scenario requires relatively small investments, between 160 and 660 million US$. The progressive scenarios A and B need significant funds: scenario A requires 1–4.5 billion US$ and scenario B 4.5–16.5 billion US$. The largest investment cost is required for the purchase of machines and equipment followed by construction costs (see Appendix E).

Table 6
Value added, imports and employment figures of all sectors per region and per scenario due to changes in the NE sugarcane–ethanol sector, in absolute and relative figures including the reference scenario.

Area	Scenarios	Value added [million US$_{2010}$]	Relative impact[a] [%]	Imports [million US$_{2010}$]	Relative impact[a] [%]	Number of jobs [×1000]	Relative impact[a] [%]
Traditional NE	Ref 2010	1.990		113		100	
	BaU2020	2.211		117		88	
	Scenario A2020	3.086		157		109	
	Scenario B2020	3.120		160		112	
Expansion NE	Ref 2010	547		49		26	
	BaU 2020	602		51		23	
	Scenario A 2020	831		67		29	
	Scenario B 2020	6236		424		174	
Rest of Brazil	Ref 2010	477		127		14	
	BaU 2020	504		134		15	
	Scenario A 2020	651		174		20	
	Scenario B 2020	1363		357		41	
NE Brazil (trad +exp)	Ref 2010	2537		161		126	
	BaU 2020	2812	11	168	4	111	−12
	Scenario A 2020	3917	54	223	38	139	10
	Scenario B 2020	9357	269	585	262	286	126
Total (Brazil)	Ref 2010	3.014		288		141	
	BaU 2020	3.316	10	302	5	126	−10
	Scenario A 2020	4568	52	397	38	159	13
	Scenario B 2020	10,720	256	942	227	327	133

[a] Impact relative to reference scenario.

Table 7
Change of employment in the sugarcane–ethanol sector in the three scenarios in absolute figures, compared to the reference situation (due to the introduction of mechanised harvest).

Area	Scenarios	Change in number of sugarcane jobs[a] (×1000)
Traditional areas NE	BaU	−16
	A	−7
	B	−7
Expansion areas NE	BaU	−4
	A	−2
	B	38

[a] A negative sign indicates a job reduction.

Table 8
Breakdown of value addition and employment for traditional, expansion and rest of Brazil areas, due to the production of ethanol and sugar in the NE, combined with the related impacts of capital investments, for scenarios BaU, A and B[a].

	Total value added (billion US$_{2010}$)			Total employment (×1000)		
	BaU	A	B	BaU	A	B
Traditional areas NE	2.2	3.1	3.1	88	110	112
Expansion areas NE	0.6	0.8	6.3	23	30	175
Rest of Brazil	0.5	0.9	2.5	17	31	82
Total	3.3	4.9	11.9	128	170	370

[a] Numbers may not add up due to rounding.

The total socio-economic impacts are the sum of the impacts of producing ethanol and sugar and the impacts of the necessary investments to produce the additional ethanol and sugar, see Table 8.

Since most of the machinery, equipment, vehicles and the construction services are provided by the CS region, this area absorbs quite a large share of the impacts generated by the investments made in the NE region, see Appendix E for more details. The employment generated by the investments made is large, reaching almost 43,000 jobs in scenario B (11,000 in scenario A and 2000 in the BaU scenario). Compared to the reference scenario, the total employment including capital goods investments, employment is increased with 21% and 164% in scenario A and B respectively, and decreased with 9% in the BaU scenario. Scenario B would add value of around 0.5% to the national GDP of Brazil and around 4% to the GDP of NE Brazil.

Depending on the scenario, the surplus electricity that can be generated by the sugarmills, 5.5 and 13.6 TWh in scenario A and B respectively, represent around 9% to 22% of the total electricity produced in the NE region nowadays (61 TWh in 2009). Potentially 10–25 million people can benefit from this in the NE region [39].

3.5. Sensitivity analysis

Two parameters are varied

- *Values of sugarcane yields*: Since irrigation has demonstrated to be the factor that contributes the most to the change in yields, the analysis is performed for different irrigation ranges. It is assumed that only large to medium sugarcane producers can afford the investment required for irrigation systems, who cover 35% of the total area, this relates to average sugarcane yields of 97 t/ha/year. As a conservative estimate, an area of 10% is assumed, relating to an average sugarcane yield of 89 t/ha/year. An upper range is assumed taking into account that policy programs facilitate and promote irrigation systems for smaller sugarcane producers, covering 50% of the area which relate to average sugarcane yields of 103 t/ha/year.
- *Amount of expansion land*: The amount of additional land for sugarcane cultivation in the future depends on many factors, e.g. policies, financial resources and evolution of the sugar and ethanol demand. 50% of the expansion area of scenario B is used as lower limit (625,000 ha). The upper range includes all

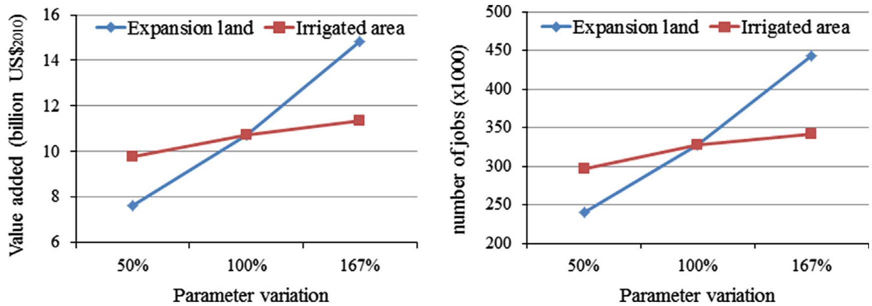


Fig. 3. Variations in value added and employment using a range for irrigated areas and expansion areas.

potential expansion areas identified by the sugarcane Zoning exercise which is 2 million ha (EMBRAPA 2009).

The results are presented in Fig. 3.

The sensitivity analysis shows that the results of the IO model are highly dependent on the amount of expansion land that is considered. Varying the amount of land from 624,000 to 2 million ha causes GDP to vary from 7.6 to 14.8 billion US$$_{2010}$, while employment varies from 240,000 jobs to 443,000 jobs. The amount of irrigated area (and thereby yield) has a much less effect on GDP and employment. This is due to the fact that the total additional production of sugarcane is much larger considering the total amount of expansion land compared to the yield change due to irrigation. Even at the lower range, so if 50% of the expansion land is considered (624,000 ha of land) this still leads to positive impacts on GDP and employment.

Other studies that use a similar methodology show that employment effects from the production of biofuel can indeed be large, although assumptions are generally very different. The study by Wicke et al. [22] on soy production in Argentina found an employment increase of 16–21% (2–2.7 M jobs) and total GDP increases by 16–25%.And in Thailand biofuel production can generate around 118,000 person-years (direct and indirect) based on biodiesel and ethanol production in 2009 [23].

4. Discussion

4.1. Input–Output analysis

An IO analysis can provide useful and quantifiable outcomes on value added, imports and employment. However, there are also several drawbacks that are inherent to this methodology, described by [22,40]. Another methodology that could be used is a General Equilibrium Model (CGE) such as described by [41]. But CGE models are more complex and require high capacities. When using inter-regional IO models, a large amount of intra and inter-regional data is needed and it is necessary to make assumptions on the dependability of inter regional trading relationships. Other uncertainties associated to inter-regional models include allocation, aggregation, imputation and balancing compared to one-single region models [27,42].

An IO table of 2004 is used to calculate the socio-economic impacts of the situation in 2010 and thus, it is assumed that the economy and the inter-sectoral linkages stay the same in the given period of time. This is a rather strong simplification because economic changes have occurred since then, for example the global financial crisis in 2007–2008. Although the Brazilian emerging market withstood the international financial crisis well, the growth in GDP fell in 2008 and 2009 and many companies had to cut their production levels and cancelled or postponed investment projects. Thus, it is uncertain whether the 2004 IO table is representative for the economic structure nowadays and it is even more uncertain for scenarios in 2020. It is therefore recommended to use more updated IO tables when applying IO analysis for medium- to long-term time periods. Furthermore, to simplify the model, the producers electricity price is assumed to remain constant, which in reality may be different. Also other prices are considered constant in an IO model, taking a learning curve into account could improve the model. This also counts for the fixed technology coefficients, that assume constant returns to scale as explained also by [40].

Other uncertainties are found in the disaggregation of the different expenditures which are allocated over the different IO sectors of the model. Due to the lack of published data this was mainly based on expert's estimations and thus, there is a margin of error in the disaggregation. However, this error is not expected to change the results significantly since the contribution of the costs that were disaggregated (e.g., agricultural inputs and repair and maintenance (R&M) costs) to the total production costs is not large.

The IO model used in this study has not considered the domestic consumption induced by new economic activities that are generated, since the initial IO tables embedded the domestic consumption data within the final demand column. Therefore, it is expected that when accounting for these induced impacts, the socio-economic impacts will be more positive than the ones presented in this research. For future research, Brazilian IO tables could be improved by separating imports and household consumption from the added value row and the final demand column respectively. This will allow calculating the impacts on trade balance and the induced effects on the economy

Although the extended inter-regional IO model developed can deliver a large amount of information (e.g., GDP and employment changes in all economic sectors of each region, income levels etc.) it cannot quantify other key socio-economic aspects. For example, the quality of labour, land conflicts and migratory issues are essential issues that will need to be tackled in a comprehensive socio-economic assessment. Furthermore, it is highly recommended to further study food competition issues and the environmental implications of expanding sugarcane.

Detailed cost–benefit analyses of the implementation of irrigation in the different producing regions of the NE are essential. This can help to gain more insight in the potential of this technology and can also attract the attention of investors and promote favourable governmental policies. It is also recommended to collect additional production costs data at a regional level to be able to assess the accuracy of different data sources together with potential yields that the sector in the NE region can achieve.

4.2. Input data and assumptions

While the biggest socio-economic impacts are found in scenario B, it is more likely that in the coming years a growth-path is

established that resembles scenario A. Most of the interviewed people agreed that the growth in the sugarcane–ethanol–sugar sector in the near-term will occur vertically (improving yields) and not horizontally (expanding land). Although in the NE region there are potential areas to grow sugarcane, as identified by the Agroecological Zoning, the better conditions of the CS (more water availability and larger pieces of land) attracts currently the biggest investors. Sugarcane producers of the NE are already expanding their businesses in areas of the CS. However, with the implementation of favourable policies and investments, scenario B can become a reality. In fact, some initiatives are now being developed in Maranhão (SINCOEX program) and Bahia (project Bahia Bio) to expand the sugarcane–ethanol sector [43]. Furthermore, the resources for investments already exist in the region. Beyond those offered by the governments of the states and by the BDN (Bank of the NE), the Federal state also helps entrepreneurs through the BNDES (Development Bank) and private funds. The direct involvement of foreign capital has also played a key role in the Brazilian sugarcane–ethanol sector. The NE has available fertile land for sugarcane cultivation together with inexpensive land prices and good access to infrastructure which are key factors from an investor's point of view.

The scenarios have assumed a certain sugar and ethanol production; however there are several aspects that influence this. The NE has become essentially a sugar producer due to the high international sugar prices and the export incentives the producers receive in the NE. This has retained the ethanol market to grow. Although international sugar prices are anticipated to remain high, it is uncertain whether the favourable quotas will continue. Ethanol is mostly consumed in Brazil and its prices are sensitive to the domestic market and idiosyncratic factors such as the evolution of the flex-fuel cars market, climate and the existence of credit [44]. The tendency of higher petrol prices together with an increasing interest for biofuels due to environmental concerns will push the demand for ethanol, creating an opportunity for the ethanol market in the NE to grow. However, the possibility to produce sugar or ethanol by mixed sugar mills, has a positive influence on the stability of income because the mills can switch production depending on the best price.

The scenarios in this analysis have only included sugarcane–ethanol production. The production of second generation ethanol from bagasse and straw is an option with large potential. Another scenario where the sector shifts from sugarcane production to other crops could also occur. However, this is not very likely because farmers in the past have tried to do so and they returned to sugarcane because it was more profitable.

The rate of mechanical harvest assumed in each scenario can vary. It is still not clear how and when the full prohibition of manual harvest will affect the hilly regions of the NE region. Amongst other reasons due to the lack of financial resources and political support in the region essential to facilitate the shift to mechanised harvesting. Lower mechanisation rates than the ones considered here will lead to less low paid jobs lost. Moreover, also wages and prices will change during this time period and hence the total impact might be larger than calculated.

By introducing higher technological levels in the sugarcane–ethanol sector, two distinct impacts might be generated; on wages paid and on the informal economy. More higher-qualified labour, as required in scenarios A and B, will have higher average salaries compared to the reference case, which is positive. But, higher technological levels such as a higher mechanisation rates, will negatively impact low-qualified workers, who might move to informal employments in the absence of a better job. To avoid this, it is essential to ensure training programs to enable low-qualified labour to access more stable and better paid jobs. However, further research is needed to understand the relationship between the current informal economy and the impacts of introducing higher technological levels in the sugarcane sector in Brazil.

The production of surplus electricity from bagasse can considerably increase the sector's revenue in the future as well as being an important contribution to the region's electricity matrix. Moreover, this can provide the additional electricity needed to irrigate the sugarcane. The high levels of fibre in the sugarcane grown in the NE together with the gradual elimination of sugarcane burning would increase the potential to generate electricity from bagasse and straw. However, a main obstacle to achieve this could be the lack of investments. Also, the small-scale production size of most of the plants in the region limits the possibilities of introducing technological improvements and increases the production costs.

A limitation of the scenarios constructed is the omission of the technological changes occurring in the sugarcane–ethanol sector of areas outside the NE region such as the CS where the productive systems are also expected to improve in the coming years. When accounting for this, the calculated impacts, in particular value added, will be larger than the presented results. Furthermore, the efficiency improvement in the livestock sector was highly simplified, this should be analysed further.

An important aspect is the large variation of the outcomes of this study by the amount of land considered and that surplus land may only become available with an intensified livestock system which requires favourable policies and the arrival of the required financial resources in the sector. Since no intensification trends of livestock production have been observed in the past years, it is essential, when considering biofuels expansion, that adequate policies and investments are implemented to achieve a more efficient livestock production without food displacement effects.

The Sugarcane Zoning (ZANE) used to identify new sugarcane areas has only been approved as a law proposal and thus, all the protected areas that the ZANE excludes are actually not fully protected yet.

5. Conclusions and recommendations

All scenarios studied increase the GDP and imports of the region compared to the current situation. In 2020 the value added by the sugarcane–ethanol sector of the Northeast (NE) region reaches up to 2.8 billion US$ (BaU scenario), to almost 4 billion US$ (scenario A) and to 9.4 billion US$ (scenario B), where the expansion areas of the NE experiment the largest growth. The impact of the sugarcane sector in the NE on the total GDP of Brazil varies from 0.2% in the BaU scenario up to 0.5% in scenario B. The potential electricity that can be generated is huge, reaching up to 9% (scenario A) and 22% (scenario B) of the total electricity currently produced in the NE region. The analysis showed that the negative impact on employment by introducing mechanical harvest is counterbalanced by the positive effects of productivity gains, the total employment in the NE region in 2020 increases with 10% in scenario A (around 12,500 jobs) and 126% in scenario B (around 160,000 jobs). A large part of the employment created will take place in the sugarcane sector. Since the newly generated jobs will require more qualified labour, complementary efforts to boost educational programs to the low-educated workers, mostly present in the sector and in the region, are desired.

The inter-regional analysis has shown that a large part of the GDP that is generated goes to those states where most industrial activities are located (due to indirect effects), which is the Central South (CS) region. Most of the machinery, equipment, vehicles and services are provided by the CS. This means that if the current

situation continues, any development in the producing states in the NE sector will not fully benefit the region because of the large dependency of the NE on the economic activities in the CS region. The little industrial activities occurring in the NE need to grow so the region can become more economically independent from the CS of Brazil.

This study has used an inter-regional IO model which has proved to be an adequate tool to assess the socio-economic impacts in the studied region and in the other Brazilian regions. It has permitted to develop a deeper understanding of the linkages within and outside the NE region. The extended model uses a more complex approach than a conventional IO analysis by using technologically different production systems and an exogenous/endogenous model. Despite the uncertainties of the method discussed before, the approach used is a good and robust tool to calculate the regional and national socio-economic impacts of different sugarcane–ethanol production systems.

The NE region has potential to be a new frontier for sugar and ethanol production. The positive socio-economic impacts that occur while developing and expanding the sector in the NE region are very large for the region and for the economy of the rest of Brazil. If the sector could be stimulated and expanded without hampering food production and causing further pressure on the land and the environment, the sugarcane–ethanol market in the NE could achieve a level of technology and sustainability as high as in the CS. This will substantially encourage regional development and economic growth.

5.1. *Specific outcomes and recommendations for the region*

There is a need for more R&D programs that can promote local solutions to the sector in the NE. Until now the NE region only tried to follow and adapt to the developments made in the CS region. Exogenous solutions from other regions have not always shown to be viable and have the same benefits for the NE region. Thus, the strengthening of R&D programs are essential, particularly in matters relating to agriculture where the correct understanding of the local factors has shown to be key in the sector's development.

Strengthening the industrial sector of the NE will reduce its dependency of the CS region, which will generate more wealth and employment locally. A stronger focus on exporting the ethanol and sugar produced to the international market to take advantages of the lower transportation costs of the NE region in compared to the CS. This could place the NE region in a more competitive position.

To ensure the accomplishment of sustainability standards in the sector, effective certification is needed. Certification should result in a win–win situation among the various actors of the supply–demand chain where a price premium paid by the demand side is received by the producers when they comply with the standards.

An increasingly common practice among producers is the rotation of sugarcane with other (food)crops such as soybeans, peanuts and beans. This enables farmers to diversify their income and is also recommended to maintain good soil conditions.

It is also vital to study and implement solutions that cushion the negative impact on labour from the introduction of mechanisation. Programs to train low-qualified labour, like currently in São Paulo, are needed. The lack of agricultural knowledge among small sugarcane producers can also be avoided by adequate training programs.

Because of the obstacles to generate electricity by small scale plants, a reorganisation of the sector by grouping the smaller units into large scale plants could bring numerous benefits to the sector such as increased electricity production for the region.

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Appendix A. Structure and description of the sugarcane–ethanol sector in the NE of Brazil

A.1. *Structure of the sugarcane–ethanol sector in the NE of Brazil*

In the NE region the production of sugarcane is located on the eastern coastal tableland called *Zona da Mata*. This area is the second biggest sugarcane production area in Brazil (and the fourth world biggest sugarcane producer) contributing with 10%, 12% and 7% of Brazilian sugarcane, sugar and ethanol output in 2010 respectively [45,46]. The states of Alagoas and Pernambuco are the main producing regions with 72% and 85% of the regional sugarcane and ethanol produced in the NE respectively [45].

The sugarcane produced in the NE is cultivated either by outgrowers or by medium and big producers (usually sugarmills). In the NE more than 90% of the sugarcane producers are small units owning less than 20 ha but producing less than 5% of the regional sugarcane produced. Most of the outgrowers cultivate the sugarcane until it is ready to be harvested and then sell it to the sugarmills who take the responsibility of other operations such as processing. Although agricultural yields in the NE are currently still low compared to yields in the CS region; better fertilisation, the introduction of irrigation and the use of improved sugarcane species, among other factors, have largely contributed to increased agricultural yields in the last 20 years [47].

The sugarcane that is produced, is processed in 76 sugarmills located in the NE region. Sugarmills can broadly be classified into three groups; (1) sugarmills that only produce sugar, which represent 9% of all plants; (2) sugarmills that can produce both sugar and ethanol. This is the dominant group representing 57% of total plants; (3) independent distilleries that only generate ethanol, which account for 34% of all the plants [48]. The large proportion of small sugarmills, processing 500,000 t or less, restrains the competitiveness of the sector in the NE compared to the CS.

The states of Alagoas, Penambuco and Rio Grande do Norte are more oriented to sugar production while all the other smaller sugarcane producing regions focus more on ethanol production. From the current 63 Mt sugarcane produced in the NE, 60% is dedicated to sugar production. Often production of ethanol in Northeast sugarmills is marginal and it is only produced to use the molasses obtained as a byproduct during sugar production. This is due to the favourable sugar export quotas the NE region has and the current high world sugar prices generated after the past water flows in important sugar producing countries such as India and Pakistan (experts, fieldwork).

A.2. Description of sugarcane production in NE Brazil

A.2.1. Planting

In the NE the sugarcane is normally planted shortly after the previous harvest and is harvested in the next year, so after 12 months. The planting period is between September and February [49]. In the CS on the other hand, sugarcane is usually planted in cycles of 18 months, with a fallow period or rotation crop in between.

The uneven topography of the NE makes it sometimes difficult to mechanise some of the operations. The three types of areas where sugarcane is cultivated in the NE can be classified as follows:

Flat areas called “chã” which are good areas for sugarcane cultivation. It is possible to mechanise all the operations (planting, fertilisation, harvest) as well as using precision agriculture, having a good management of nutrients, and to irrigate. Here productivities of 80 t/ha are easily reached.

Hilly areas called “costa” which are frequently found in the North of Alagoas and Pernambuco and reach slopes up to 40%. In very steep areas (> 18% slope gradient) all the operations of preparation of the soil, fertilisation and harvesting need to be done manually which increases significantly the labour costs and therefore, the final production costs. Here productivities are 50 t/ha and lower. Besides, the sugarcane collected in these areas has lot of impurities and requires more washing which leads to more losses of the total reducible sugars than that cane cultivated in flat areas. These areas are considered inappropriate for the cultivation of sugarcane

Shallow areas closer to the sea side which are called “varzea” which are flat areas but their proximity to the sea side soils are often wet making difficult to use mechanical harvest. Here moderate to high productivities (up to 80 t/ha) can be reached

A.2.2. Fertilisation

Sugarcane demands high amounts of nutrients. In order to improve the quality of the sugarcane and sugar yields on a sustainable basis, it is essential to apply adequate amounts of nutrients (N, P and K). The application of ferti-irrigation, where industrial waste (stillage and filter cake) are used as fertilizers, decreases the consumption of traditional fertilizers and has proven to improve yields [50].

A.2.3. Weed and pests control

In order to avoid yield losses it is essential to use products that combat diseases, pests and weed growth. The methods to avoid germination of weeds vary depending on the slope of the cultivated area. In flat areas, it is common to reduce the spacing for weed control. Mechanised harvesting can also reduce the use of herbicides because when the sugarcane is not burned, the straw stays on the soil surface and avoids the germination of weeds.

A.2.4. Irrigation

Sugarcane has a high water requirement in comparison to other crops. The water demand is estimated to be between 1100 and 1500 mm with an evapotranspiration rate of 4–7 mm/day. Water supply, especially during critical stages, is essential to ensure good agricultural productivities.

While most of the sugarcane cultivated in the CS region of Brazil does not need to be irrigated due to the frequent rains, sugarcane irrigation in the NE region is an essential factor. The sugarcane is cultivated in the coastal regions (Zona de mata) where the average annual rainfall is 1500 mm. However, the rainfall is heavily concentrated between March and May. If water could be captured during this 3 month period, this would be sufficient for irrigation during the dryer period. Experiments executed by Embrapa in a sugarmill located in Piauí, have demonstrated the potential of irrigation in the NE; yields have increased more than 2 times [51]. Currently most of the sugarcane in the NE is cultivated using salvation irrigation: water (< 200 mm) is supplied during critical periods to prevent water deficits.. The most commonly used systems are sprinkler systems with wheel-line and pivot systems. Drip-irrigation is only used by large sugarmills due to its high investment cost. Another type of irrigation is ferti-irrigation: vinasse (a by-product from the ethanol production process) is used in a drip-irrigation system, in this way both fertilizers and water is provided to the sugarcane. Areas with high slopes are normally not irrigated due to the difficulty of implementing an irrigation system. More and more sugarcane in the NE is being irrigated, the irrigated area of the *Coruripe* sugarmill for example, has grown from 2700 ha to the current 25,000 ha in 25 years.

A.2.5. Improved sugarcane species

Improved sugarcane varieties adapt to the climate conditions, soil type and harvesting system (manual or mechanised) of the different regions. They are also resistant to pests, diseases and water stress as well as having high concentration of sucrose in the storage tissue [52]. The main sugarcane varieties grown in the NE are RB and SP varieties which account to more than the 80% of the region´s inventory. A very successful variety found recently is RB 92579 which is resistant to drought and can be cultivated in steep slope areas. This variety has proved to improve productivities with 30% and increase the sucrose content of the sugarcane in 20% (research centre, fieldwork).

A.2.1.1. Harvest. The whole sugarcane cycle in the NE region is typically a 5 years-cycle which includes 4 harvests. However, in fields with high slopes it is common to replant the sugarcane after 4 years, while in flatter areas the sugarcane cycle can reach 8–12 years. Throughout these cycles the productivity decreases and therefore, it is normally more cost-effective to replant the crop after on average 5 years. The harvest season typically starts in September and ends in March. Depending on the sugarcane variety the first harvest is made after 12–18 months of planting.

A.3. Description of sugar, ethanol and electricity production in NE Brazil

A.3.1. Processing

When the industrial yields are compared with those obtained by the CS region, it can be said that the sugarmills in the NE are slightly less efficient in the conversion of sugarcane to ethanol due to the lower technological levels and the poorer quality of the sugarcane processed. The sugarcane cultivated in hilly areas has often less TRS. This is because this sugarcane drags more impurities when it is being harvested which needs more washing and thus, increasing the sugar loss. The industrial losses of the sugarmills in the NE are around 11% while in the CS the average is 8%.

A.3.2. Electricity generation

Sugarmills need three kinds of energy to process the sugarcane: (1) thermal energy for heating and concentration processes; (2) mechanical energy for milling and other mechanically driven systems (pumps and large fans) and (3) electric power for powering pumping, control systems and lighting. This energy is provided by co-generating bagasse in the mill's boilers. In areas where mechanical harvest is implemented, sugarcane straw can be also used as a fuel but this new practice is not being used in the NE region yet.

The processing of 1 t of sugarcane yields about 140 kg of dry bagasse that can generate 500–600 kg of steam where approximately 400–600 kg of steam or 12 kWh/t of sugarcane processed are consumed in the industrial process [53]. The bagasse obtained in the NE region has 12% more fibre content than the bagasse from the sugarcane cultivated in the CS region which is an advantage for the electricity generation process [46].

Sugarmills sometimes use the surplus electricity produced to sell in the energy market and also to consume in the agricultural process when irrigation is implemented. It was found that sugarmills in the NE using irrigation prefer to sell all the surplus electricity generated and buy the electricity needed for irrigation since this is more profitable (sugarmills, fieldwork). Currently the amount of plants in the NE area selling their exceeding energy is negligible. Sugarmills in the NE region can be considered small to medium units having an installed capacity of less than 30 MW [54]; research centre, fieldwork). There are in total 38 sugarmills in the NE that have electrical capacity installed. 17 sugarmills that have an installed electrical capacity < 9 MW, 16 of 10–29 MW and only 5 30–60 MW [54]; research centre. Units located in the CS region have 60–100 MW installed capacity.

Appendix B. Additional data for scenario descriptions

B.1. Business-as-Usual scenario

In order to project growth tendencies for this scenario the historical evolution of sugarcane production and of the area cultivated are taken into account, see Fig. B1. Between 1990 and 2000, cultivated land and sugarcane production in the NE of Brazil rapidly decreased. During this period, many sugarcane producers stopped production because of the difficulties trying to compete with the CS producing region. From 2000 to 2009 a slow recovery of the sector took place.

The recuperation was slightly faster in the last years because of the expansion of sugarcane in Rio Grande do Norte, north of Alagoas and Paraiba and because of the slightly better agricultural practices (e.g., use of improved sugarcane species). These changes are reflected in the yields which have increased in the past 20 years (between 1990 and 2009) with on average 0.9 %/year, see Fig. B2.

Regarding the industrial yields, no improvements have taken place in the last 15 years as depicted in Fig. B3. Yields remained at 80.6 L/t for ethanol production (for distillery) and at 135.5 kg/t for sugar production (for sugar factories).

The same configuration of sugar and ethanol production in each sugarmill is maintained, see Table B1. This is used in the IO model to distribute the total production of sugarcane, sugar and ethanol among the different plant types. Sugarmills will have an average processing capacity of 1,100,000 t of sugarcane. In sugarmills that produce ethanol and sugar (mixed sugarmills) 64% of the sugarcane is directed to produce sugar and 36% to produce

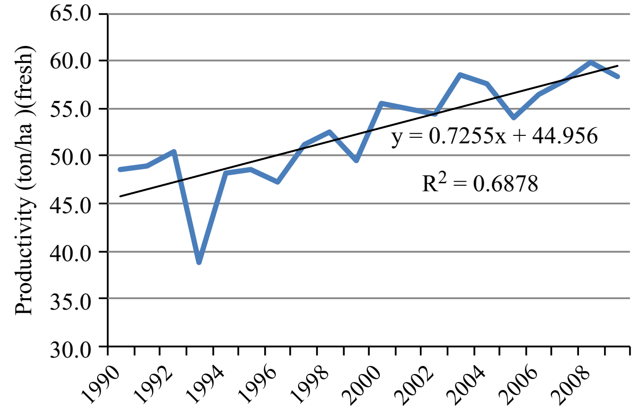


Fig. B2. Evolution of sugarcane productivity in the NE since 1990. Elaborated with data from IBGE [47].

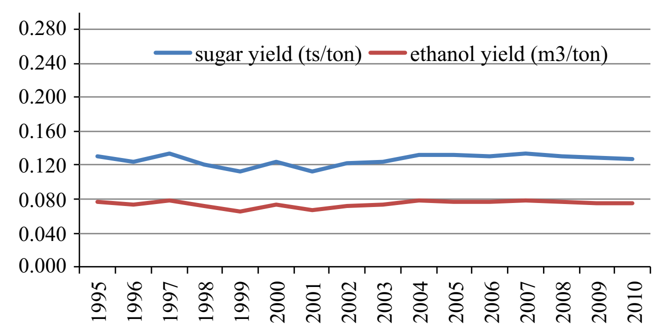


Fig. B3. Evolution of sugar and ethanol yields in the NE region from 1995. Calculated from data from association of sugarmills (fieldwork) and data from [48].

Table B1
Current share of sugar and ethanol production of each type of sugarmill.

	Sugar factory (%)	Distillery (%)	Mix sugarmill (%)	Source
Sugarcane milled	11	32	57	[55]
Sugar production	24		76	Own calculations[a]
Ethanol production		61	39	Own calculations[b]

[a] Calculated using the sugarcane milled in each plant type and a sugar yield of 135.5 kg/t cane (for sugar factory) and of 86.7 kg/t cane (for mix sugarmill).
[b] Calculated using the sugarcan milled in each plant type and an ethanol yield of 80.6 L/t cane (for distillery) and of 29 L/t cane (for mix sugarmill).

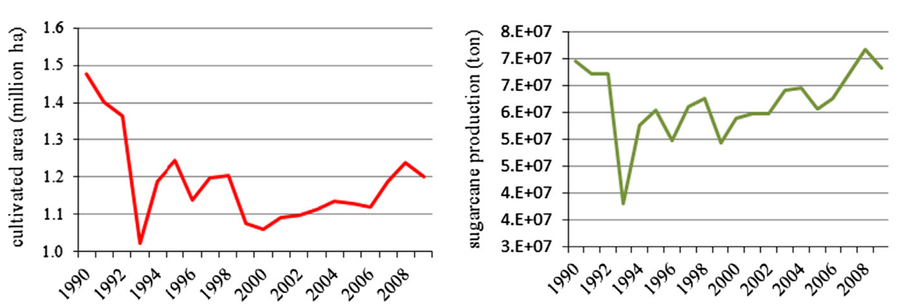


Fig. B1. Evolution of cultivated area with sugarcane in the NE since 1990. Elaborated with data from IBGE [47].

ethanol. From the total sugarcane produced, 59% is used for sugar production and 41% for ethanol production as currently practiced in the NE region.

B.2. Scenario A

Key parameters that influence productivity in the NE are irrigation and the use of improved sugarcane species [46]. Two types of irrigation methods are assumed in this scenario; drip irrigation which is most efficient in water and energy consumption but is also more expensive, and sprinkler-irrigation systems which are cheaper but are less water and energy efficient. In 2020 it is assumed that drip-irrigation and sprinkler irrigation will be implemented in 30% and 70% of the total irrigated area respectively. Furthermore, rain-water capture installations are assumed to be built that supply the total amount of irrigation water that is required. The energy needed for the irrigation system will be provided by the electricity generated from bagasse. Thus, only the large and medium sugarmills will implement irrigation in their production systems, because this investment is too high for small producers. Therefore, only 35% of the total cultivated area will include supplementary and full irrigation. The rest of the areas maintain salvation irrigation (160–200 mm) as currently practised.

Ferti-irrigation provides a solution for better water and fertilisation management since water and fertilizers are delivered to crop simultaneously through the drip irrigation system. In this study is it assumed that that the current levels of fertilizers and agrochemicals do not need to necessarily increase to enhance yields but they can be more efficiently used by having better agricultural management.

The total cultivated area in this scenario has excluded all those areas with slopes higher than 18%. This is done because high slopes areas are economically unfeasible for the cultivation of sugarcane on a large scale due to: (1) impossibility to implement mechanical harvest with the technology that currently exists (2) these areas are inaccessible and need frequently intensive use of labour for other operations such as tilling, planting, fertilisation and irrigation which increases the cost of production; (3) the sugarcane in these areas has many impurities which needs more washing and results in the correspondent loss of the total reducible sugars. Areas with slope gradients higher have been estimated to represent 30% of the total area by experts during fieldwork. Then total sugarcane area considered in this scenario is 0.88 million ha (30% of the current 1.1 million ha).

By combining all the aspects explained above the potential productivities that can be achieved are very large. Table B2 depicts the projected productivities considered for this scenario. A division has been made in (1) Areas belonging to small producers that use salvation irrigation (5.7 thousand ha or 65% of total area) and (2) Areas belonging to large and medium producers that incorporate supplementary and full irrigation (3.1 thousand ha or 35% of total area).

Between 2010 and 2020 the annual growth rates for the medium/large and small sugarcane producers are 7% and 4% respectively. These yields have been estimated on what is currently being achieved by using some of these practices and by consulting agricultural sugarcane experts during fieldwork.

The level of mechanical harvest in this scenario for 2020 is 50% that corresponds to those areas with slopes lower than 12%.

The improvements made in the agricultural process will also enhance the quality of the sugarcane received in the sugarmill. For example, mechanical harvested sugarcane will replace the conventional washing by dry-washing, reducing the sugar losses.

Table B2
Current and projected sugarcane yields (t/ha/year) in 2020 for scenario A.

Year	Areas with salvation irrigation, use of better sugarcane species and more efficient fertilizers and agrochemicals use (65% of total area)	Areas with supplementary and full irrigation, use of better sugarcane species and more efficient fertilizers and agrochemicals use (35% of total area)	Average productivity
2010	57	57	57
2020	85	120	97

Table C1
Matrix and equations used under the industry-based technology approach and commodity-based technology approach for a two-technology example.

		1 T_1	2 T_2	3 Total ethanol	4 Total sugar
1	T_1	$\beta_{1,3}\,X_1$	$\beta_{1,4}\,X_1$		
2	T_2	$\alpha_{2,3}\,X_2$			
3	Total ethanol			$X_3=\beta_{1,3}\,X_1+\alpha_{2,3}\,X_2$	
4	Total sugar				$X_4=\beta_{1,4}\,X_1$

Table C2
Sector aggregation in extended inter-regional IO model.

Sector #	Sector name in the extended IO model	Guilhoto et al. [37] sector #
1	Animal production	3
2	Sugarcane	1
3	Ethanol	15
4	Sugar production	6
5	Electricity production	40, 41
6	Other crops	2
7	Fuels extraction and mining	4, 5
8	Food, tobacco, textile and footwear	7, 8, 9, 10
9	Wood products and others (books, Cds)	11, 13, 39
10	Paper and office equipment	12, 31
11	Coke and refined petroleum products	14
12	Fertilizers and other chemical products	16
13	Resine, plastic and rubber products	17, 23
14	Pharmaceutical, cleaning and veterinary products	18, 20
15	Agrochemicals	19, 21
16	Paints, varnishes and other chemical products	22
17	Cement, concrete, glass and keramic products	24
18	Mineral products (non-metalic)	25
19	Steel and metal products	26, 27, 28
20	Machines and equipments	29
21	Domestic and hospital appliances	30, 34
22	Electrical machines and equipment	32, 33
23	Motor vehicles (automobiles, trucks and buses)	35, 36
24	Accessories for vehicles	37, 38
25	Water and gas supply	43
26	Construction	44
27	Electricity transmission and distribution	42
28	Commerce	45, 46, 47, 48, 49, 50
29	Transport, storage and post	51
30	Services to companies	52, 57
31	Finance and insurance	53
32	Accomodation and food services	54, 56
33	Repair and maintenance	55
34	Education, health and public administration	58, 59, 60, 61, 62, 63

Improved sugarcane varieties can also help to achieve high sucrose contents. This will be translated into gains on industrial yields. This scenario considers also a modernisation of the industrial equipment. The extraction process for example can be improved by introducing diffusers with higher extraction capacity [53,56].

The progressive implementation of mechanical harvest and the high fibre content of the sugarcane in the NE region, makes the generation of surplus electricity more feasible. The sugarmills need to implement some changes such as the installation of high pressure boilers.

The potential annual growth of efficiency reported by the Energy National Plan for Brazilian plants that can be achieved by including the improvements explained above are 0.56% for distilleries and 0.35% for sugar factories [57]. For scenario A current average yields for distilleries and sugar factories have been taken which are 80.6 L/t and 135.5 kg/t respectively [58] and projected for the year 2020 with the same growth rate considered for a Brazilian sugarmill. In this scenario it is assumed that all the sugar and ethanol produced comes from distilleries and from mix sugarmills, thus sugar factories will not exist. This is because

Table C3
Structure of the extended inter-regional IO model that is used in this study.

	Traditional areas NE					Expansion areas NE					Rest of Brazil		Final demand			Total production output		
	Technologies			IO sectors		Technologies			IO sectors		IO sectors							
	Sc_Man 10	…	(Et+Sug+El)20	S_1	S_{34}	Sc_Man 10	…	(Et+Sug+El)20	S_1	S_{34}	S_1	S_{34}	Y_{TRAD}	Y_{EXP}	$Y_{rest\ Br}$	X_{TRAD}	X_{EXP}	$X_{rest\ Br}$
Traditional areas NE																		
1																		
…																		
15																		
16																		
…																		
50																		
Expansion areas NE																		
51																		
…																		
66																		
67																		
…																		
101																		
Rest of Brazil																		
102																		
…																		
136																		
Imports																		
Taxes																		
Labour																		
Kapital																		
X^T																		

Table D1
Cost items of sugarcane production in NE Brazil adapted from [49].

Sugarcane production costs	$US\$_{2010}/t$[a]		$US\$_{2010}/t$
Soil preparation and planting	5.5	*Administration*	5.7
Mechanised operations	0.9	Owner/manager remuneration[b]	0.5
Labour	1.3	Administration costs	5.2
Inputs	3.3	*Depreciation*	1.8
Fertilizers, agrochemicals application and others	9.3	Facilities[c]	0.5
Mechanised operations	1.6	Irrigation/ferti-irrigation	0.4
Labour	1.3	Machines	0.9
Inputs	6.4	*Capital remuneration*	2.0
Harvest	8.7	Machines	1.2
Mechanised operations	2.2	Facilities[c]	0.0
Labour	6.5	Working capital/interest	0.4
Transport of sugarcane	3.4	Agricultural tillage system	0.3
Land remuneration	3.6	Irrigation/ferti-irrigation	0.1
Own land	2.2		
Land leasing	1.4		
Total agricultural cost ($US\$_{2010}/t$)		40.0	

[a] The monetary values in ESALQ [49,58] are converted from Brazilian real ($R\$_{2008}$) to $US\$_{2010}$ using the inflation rate between 2008 and 2010 in Brazil of 15% and the exchange rate of 2010; 1US$ = 1.7594 R$ [65,66]. Furthermore, it is assumed that no significant changes in costs have occurred other than inflation.
[b] Only applicable to outgrowers with a high number of self-employeed workers.
[c] These include offices, house for staff, grids for electricity, dams, machine shed and water treatment station.

currently the majority of the sugarmills are mix sugarmills (57%) and distilleries (34%). Since the sugar factories are only a minority (9% of all sugarmills) the tendency is that they disappear so all production will come from the other types of sugarmills. Thus, scenario A assumes that 60% of the sugarcane produced is processed in mix sugarmills and 40% in distilleries. It will also assume that 59% of all sugarcane produced will be directed for sugar production and 41% for ethanol production, as it is currently being done. In order to process the additional sugarcane produces as a result of the productivity gains, new sugarmills will need to be constructed. The processing capacity of the new sugarmills constructed will be 2,000,000 t of sugarcane which is larger than the average capacity nowadays of 1,100,100 t. This will bring along some economic benefits from the scaling. It has been estimated that the construction of 43 new sugarmills will be required to process the additional sugarcane produced by 2020.

B.3. Scenario B

This scenario is an extension of the previous scenario A and it assumes an expansion of the sugarcane–ethanol sector in suitable areas of the NE region. Potential areas have been identified by using the Agroecological Zoning of the NE of Brazil (ZANE) developed by the Ministry of Agriculture and Supply of Brazil (EMBRAPA 2009).

ZANE combines different types of information such as soils, climate and water resources to identify and quantify the most favourable areas to grow sugarcane. The restrictions imposed by the Zoning are

- Areas should have a minimum annual rainfall of 1500 mm;
- Areas with hydric shortfall less than 150–200 mm were excluded;
- Areas need to have temperatures between 18 °C and 28 °C;
- Areas that do not go below 2 °C to avoid the risk of hoar-frost and;
- Exclusion of areas with inappropriate soil types to grow sugarcane.

The following types of areas have been excluded for sugarcane expansion:

- Land with slopes higher than 12%;
- Areas with native vegetation, forest, dunes and mangroves;
- Environmental protected areas;

Table D2
Data related to sugarcane harvesting.

	Value	Data source
Diesel consumption manual harvest (L/ha/year)	167	[3]
Diesel consumption mechanical harvest (L/ha/year)	243	[3]
Investment conventional harvest machine (US$$_{2010}$)	540,747	ESALQ [49,58]
Investment advance harvest machine (US$$_{2010}$)[a]	811,120	(expert, fieldwork)
Discount rate (%)	15%	(expert, fieldwork)
Useful life (years)	10	(expert, fieldwork)
Annual payment conventional harvest machine (US$$_{2010}$)	107,745	[b]
Annual payment advanced harvest machine (US$$_{2010}$)	161,617	[b]
Productivity conventional harvest machine (t/day)	800	(expert, fieldwork)
Productivity advance harvest machine (t/day)	1000	(expert, fieldwork)
Working time of harvest machine (days/year)	150	[14]
Working time sugarcane cutter (days/year)	180	[14]
Number of employees needed per harvest machine	6	(sugarmills, fieldwork)

[a] Harvest machine able to work on slopes > 12%.
[b] Annual payment was calculated as: $A=(P(1+r)^n)/((1+r)^n-1)$ where P is the loan amount (investment), r the discount rate and n the total number of payments (useful life).

Table D3
Data related to sugarcane irritation, considered in scenarios A and B.

Irrigation	Drip-irrigation	Pivot-irrigation	Data source
	Value	Value	
Implementation costs (US$$_{2010}$/ha)	4064	2687	(sugarmill, fieldwork)
Useful life (years)	10	10	ESALQ [49,58]
Discount rate (%)	15%	15%	(expert, fieldwork)
Salvage value (%)	0	0	ESALQ [49,58]
Annual payment (US$$_{2010}$/ha)	810	535	[a]
Operational costs (US$$_{2010}$/ha)	1274	583	(sugarmill, fieldwork)
Electric energy	140	186	(sugarmill, fieldwork)
Repair and maintenance	739	245	(sugarmill, fieldwork)
Labour	395	152	(sugarmill, fieldwork)
Water used (mm/year)	560	300	(sugarmill, fieldwork)
Electricty price (US$$_{2010}$/Mwh)	48	48	[37, 39]
Water storage system			
Investment dam of 57,000 m^3 (US$$_{2010}$/unit)	9,831,761		(sugarmill, fieldwork)
Discount rate (%)	15%		(expert, fieldwork)
Useful life (years)	25		ESALQ [49,58]
Salvage value (%)	10%		ESALQ [49,58]
Annual payment (US$$_{2010}$/unit)	1,520,968		[a]
Annual rainfall in the coastal region of the NE (mm)	1500		[11]

[a]Annual payment was calculated as: $A=(P(1+r)^n)/((1+r)^n-1)$ where P is the loan amount (investment), r the discount rate and n the total amount of payments (useful life).

Areas with indigenous tribes;
Mining areas and;
Areas where crops are cultivated.

The sugarcane Zoning is based on maps and data from 2002. Currently Embrapa is developing a newer version with more recent data ("Probio" project). For more information about the methodology used in the Zoning see EMBRAPA solos [59].

ZANE makes a classification between high, medium and low potential areas taking into account the type of soil of each area. High potential areas include clay soils and can reach productivities higher than 80 t/ha. Medium potential areas have clay-sandy soils and can achieve productivities from 60 t/ha to 80 t/ha. Low potential areas have sandy soils which lower the productivity to 60 t/ha. This scenario has considered only land identified as high and medium potential to ensure agricultural productivities are high.

ZANE also takes into account the land use of the areas considered. As mentioned before, areas occupied with other crops are excluded so competition with food production is minimised. The potential expansion areas are classified as (1) extensive livestock land and (2) livestock/agricultural land. This last one includes areas with a continuous change in their use and that could not been identified clearly as 100% agricultural or 100% livestock land. For scenario B this last group has not been considered as sugarcane potential expansion areas to avoid any possible competition with food crops, thus only extensive livestock areas have been included for the scenario.

According to ZANE the extensive pasture areas with high and medium potential sum a total of 1.2 million ha and they are located in the provinces of Bahia, Maranhão and Piauí. Most of these areas (approximately 87%) are located in Bahia and Maranhão.

Since the expansion of sugarcane in this scenario takes place in areas where cattle is being fed, it is important to consider the livestock land needed to meet food consumption in 2020. In order to do this, expected population growths in the NE region were taken into account to calculate the amount of pasture land needed to satisfy their food consumption. Information about population growths of the NE region was used from the Brazilian statistical account database [60]. During the last 20 years the population in the NE region grew annually with 1.1%. With this growth rate it can be expected that population will increase from the current 53 million habitants to about 59 million (by 2020). The current land used for livestock production in the NE is nearly 33 million ha [61]. This is the land use occupied by the current extensive livestock of the NE region, developed over large tracts of land, with cattle loose and without major application of technological resources and financial investments. The livestock sector in Brazil has an average

Table D4
Change in cost and crop lifetime for technologies related to irrigation.

Annual cost change ferti-irrigation system[a]		Data source
Seedling	45%	[72]
Implementation	45%	[72]
Fertilisation and other chemical application	45%	[72]
Agricultural inputs	101%	(expert, fieldwork)
Lifetime crop		
Irrigated system (year)	11	(expert, fieldwork)
Non-irrigated system (year)	5	[72]

[a] When costs change <100% means cost reduction from the non-irrigated system and when the change is >100% means costs increase.

Table D6
Cost items of sugar and ethanol production in NE Brazil, based on ESALQ [49,58].

Industrial production costs	$US\$_{2010}/t$	$US\$_{2010}/ts$	$US\$_{2010}/m^3$
Sugarcane costs	36.1	266.3	448.0
Operational costs	32.6	240.7	404.5
Sugarcane from outgrowers	30.8	79.9	132.2
Sugarcane from the sugarmills	33.6	160.8	272.3
Depreciations	1.2	8.6	14.6
Opportunity costs of land and capital	2.3	17.1	28.9
Industrial costs	13.1	100.4	150.7
Industrial operations	6.5	48.5	77.5
Labour	2.2	16.5	28.0
Industrial inputs	1.5	12.2	15.9
Chemical	0.8	5.3	12.1
Electrodes	0.1	0.5	0.9
Lubrificant and fuels	0.1	0.8	1.3
Electricity	0.1	1.0	1.6
Packing	0.4	4.7	0.0
Maintenance[a]	2.7	19.8	33.5
Material	1.9	14.2	24.1
Services	0.8	5.5	9.4
Industrial depreciation	2.4	18.5	26.2
Industrial capital costs	4.3	33.4	47.1
Administration costs	4.5	33.4	56.6
Labour	1.7	12.7	21.5
Inputs and services	2.1	15.7	26.5
Working capital	0.7	5.1	8.6
Total industrial cost	53.7	400.2	655.4

[a] Maintenance includes: repair of motors, pumps, electrical installations, valves, painting and cleaning.

Table D5
Assumptions adopted in the industrial cost calculation of NE Brazil by ESALQ [49,58].

	Unit	Value		Unit	Value
Quality of the sugarcane			Productivity		
Pol (sucrose content)	%	14	Hours for milling per year	h	3628
Fibre content	%	13	Hours without production per year	h	1041
Purity of sugarcane juice	%	84	Efficiency	%	78
Total reducing sugars	kg/t	160	Production mix		
Industrial yields			% of sugarcane for sugar production	%	64
Cane washing	%	90	% of sugarcane for ethanol production	%	36
Industrial losses	%	11	Production of by-products		
Fermentation efficieny	%	85	Bagasse	kg/t	304
Destilation efficieny	%	99	Filter cake	kg/t	33
Molasses purity	%	45	Vinasse	L/L	15
Milling capacity sugarmill	Mt	1.1	Electricity production	MWh	31,812
Production of sugar and ethanol					
White sugar	%	55			
Hydrated ethanol	%	42			

efficiency of 1 heads/ha where the NE is known to have one of the lowest productivities in their livestock production [62]. Considering the expected population growths, the land use will need to expand to 36.6 million ha by 2020. However the same amount of cattle fed in the current extensive system could become much more efficient which is what this scenario has considered.

An intensification of the livestock sector can free up land that could be used for the sugarcane expansion. The following calculations show the amount of land that can be freed up when using a slightly more efficient production system. It is assumed the livestock sector in the NE today has 2 heads/ha which is a number in between the figures given by the average number for Brazil (1 head/ha) and by the livestock areas identified by the ZANE (4 heads/ha). In order to meet the projected food demands explained above, livestock will be intensified from 2 heads/ha to 3 heads/ha. This is a very reasonable intensification and it can still be considered as an extensive production system. Then, the land use needed to meet future food demands in 2020 can be reduced from 36.6 million ha to 24.4 million ha freeing up 12.2 million ha. As it can be seen, the land needed to meet food demand is lower than the current land use for livestock (33 million ha) and higher than the amount of areas considered in this scenario (1.2 million ha). This means that a slight intensification of the livestock sector will free up enough land to cultivate sugarcane. Note that only food demand in the NE region has been considered in the calculations and not world food demand. It could be assumed that future meat exports can be achieved by intensifying a bit more the livestock sector in the NE region. Besides, the land needed for this could be located in the areas identified as low potential areas for sugarcane expansion and excluded in this scenario which are nearly 1.5 million ha according to the Agricultural Zoning.

The majority of the areas identified in the province of Bahia are close to the current sugarcane cultivated areas and the port of Salvador which geographically is a good location for international exports. Another port of large depth is planned to be built in the coastal city of Ilhéus, which will be even closer to the sugarcane expansion areas. The areas identified in the state of Maranhão have roads that connect to a large port with sufficient depth to accommodate 400,000 t capacity boats. The port is currently being modernised to store large quantities of liquids for a future ethanol and biodiesel production [63]. A large project ("*ferroviaria transnordestina*") is being carried out in the NE region to construct a railway that will connect the interior areas with the coastal areas of several Northeastern states. This railway will connect the inner part of Piauí (and considered here as sugarcane expansion areas) with the port of São Luis. Moreover, the government, in particular in the state of Maranhão, is willing to develop the sugarcane–ethanol sector and to provide the necessary support to achieve this goal as it is currently being done with the *SINCOEX* program [63,64].

The same technological levels for the agricultural and industrial processes assumed for scenario A are applied to scenario B. The only difference is that the sugarcane production in the expansion areas is presumed to be used for ethanol production so all new plants constructed will be distilleries. It has been estimated that 104 new sugarmills will be required to process the additional sugarcane produced by 2020.

Appendix C. Construction of extended inter regional IO model for case study NE Brazil

C1. Example industry-based approach

In order to describe the theoretical framework of an IO model with mix technologies an example is given here, based on Cunha and Scaramucci [69]. Assuming an economy with the following 7 sectors:

S_1: manually harvested sugarcane;
S_2: mechanically harvested sugarcane;

Table D8
Contribution of the different items to the total equipment costs [49,58,70].

Components of equipment	Distillery (%)	Sugar factory (%)	Mix sugarmill (%)
Steam generator	20	25	23
Reception and extraction system	25	20	22
Destillery	30	15	20
Sugar processor	0	15	10
Turbine/power generator	10	10	10
Others	15	15	15

Table D7
Parameters for sugarmills that use conventional and progressive technologies based on [49,58,70] and interviews.

	Destillery	Sugar factory	Mix sugarmill
Conventional sugarmill			
Capacity (Mt)	1.1	1.1	1.1
Investment (US$$_{2010}$/t)	66	79	74
Equipments	39	47	44
Electromechanical set-up	5	6	5
Construction	9	10	10
Electrical instalations	5	6	6
Instruments/automation	1	2	1
Services of engineering, thermal insulation and painting	7	8	7
Progressive sugarmill			
Capacity (Mt)	2	NA[a]	2
Investment US$$_{2010}$/t)	110	NA[a]	120
Equipments	57	NA[a]	63
Electromechanical set-up	7	NA[a]	7
Construction	12	NA[a]	14
Electrical instalations	8	NA[a]	8
Instruments/automation	2	NA[a]	2
Services of engineering, thermal insulation and painting	9	NA[a]	10
Equipment for the production of surplus electricity	16	NA[a]	16
Pressure boiler (bar)	43	NA[a]	43
Surplus electricity generated (KWh/t)	49	NA[a]	46

[a] Means not applicable (this analysis excluded sugarmills where only sugar is produced in the progressive scenarios (A+B).

Table D9
Data related to employment used in the IO analysis.

Type of employment	Salary (US$$_{2010}$/month)		
Data related to employees[a] in the sugarcane sector			
Low qualified employee	317		
Medium qualified employee	475		
High qualified employee	633		
	Contribution to labour costs[b]		
Planting and application of agricultural inputs	24–52%		
Harvest	59–9%		
Administration and management	18–39%		
	Salary (US$$_{2010}$/month)	Number of employees	Contribution to labour costs (%)
Data related to employees in a distillery[c]			
Low qualified employee	338	178	41
Technician	455	59	19
Administration employee	568	32	13
Coordinator	1137	13	10
Responsible for the department	3410	5	12
Manager	7957	1	5

[a] Sugarmills and experts, fieldwork.
[b] Calculated with data from [49,58]. The first number in the range given applies when 100% manual harvest is done and the second number is when 100% mechanical harvest is done.
[c] [49,58].

Table D10
Cost items during production and processing of sugarcane and their associated sectors in the IO table.

Costs items	IO Sector name	IO sector number
Mechanical operations		
Diesel and lubricants	Coke and refined petroleum products	11
Repair and maintenance		
Resine, plastic and rubber products	Resine, plastic and rubber products	13
Steel and metal products	Steel and metal products	19
Electrical machines and equipment	Electrical machines and equipment	22
Accessories for vehicles	Accessories for vehicles	24
Hired repair and maintenance services	Repair and maintenance services	33
Agricultural inputs		
Fertilizers	Fertilizers and other chemical products	12
Lime and plaster	Mineral products (non-metalic)	18
Agrochemicals	Agrochemicals	15
Seeds	Sugarcane	2
Maturator, dissicant	Fertilizers and other chemical products	12
Industrial inputs		
Sugarcane	Sugarcane	2
Chemical	Paints, varnishes and industrial chemical products	16
Electrodes	Electrical machines and equipment	22
Lubrificant and fuels	Coke and refined petroleum products	11
Electricity	Electricity production	5
Packing	Resine, plastic and rubber products	13
Irrigation equipment		
Electric energy equipment	Electrical machines and equipment	22
Administration		
Finance and insurance	Finance and insurance	31
Water and gas	Water and gas supply	25
Services to companies	Services to companies	30
Accomodation and food services	Accomodation and food services	32
Office material	Paper and office equipment	10
R&D for new sugarcane species	Services to companies	30
Labour	Labour	
Owner/manager remuneration	Labour	
Land remuneration	Capital	
Depreciation	Capital	
Capital remuneration	Capital	

S_3: ethanol produced in a sugarmill that produces both ethanol and sugar;
S_4: ethanol produced in distillery;
S_5: total sugarcane;
S_6: total ethanol and;
S_7: rest of the economy.

The intermediate deliveries between the sectors are expressed with the technical coefficients a_{ij}. The production in sectors S_5 and S_6 are linear which means that the required inputs can be combined in any ratio while all the other sectors are described by the regular Leontief function.

The total sugarcane produced (sector 5) receives its inputs from the manual harvested sugarcane sector (sector 1) and from the mechanical harvested sugarcane sector (sector 2). For those sectors that consume sugarcane (e.g. the ethanol sector) it is not important how the sugarcane was produced. The outputs of sectors 1 and 2 can be written as

$$X_1 = \alpha X_5 \tag{C1}$$

$$X_2 = \beta X_5 \tag{C2}$$

Table D11
Contribution of the different cost items to the total mechanisation costs, agricultural inputs and administration costs.

Costs items	Contribution of each item[a] (%)	Data source
Mechanisation costs		
Fuels	48	(Experts, field work)
Lubrificants	8	(Experts, field work)
Repair and maintence of equipment	45	(Experts, field work)
Agricultural inputs costs		
Fertilizers	53	(Experts, field work)
Lime and plaster	7	(Experts, field work)
Agrochemicals	16	(Experts, field work)
Seeds	21	(Experts, field work)
Other chemical products (maturator, dissicant)	3	(Experts, field work)
Administration costs		
Repair and maintenance of facilities	35	[67]
Finance and insurance	32	[67]
Water and gas	20	[67]
Services to companies	8	[67]
Accomodation and food services	3	[67]
Office material	2	[67]

[a] Note that the sum of the individual contributions can be slightly higher than 100% due to the number's rounding.

where α and β are the contribution of the manual and mechanical harvested sugarcane respectively to the total sugarcane produced. It is clear that

$$\alpha + \beta = 1 \tag{C3}$$

$$0 < \alpha,\ \beta < 1 \tag{C4}$$

Analogously the total ethanol produced can be written as

$$X_3 = \gamma X_6 \tag{C5}$$

$$X_2 = \delta X_6 \tag{C6}$$

where γ is the contribution of the ethanol produced in a mix sugarmill that produces both ethanol and sugar and δ is the contribution of the ethanol produced in a distillery.

Applying the basic IO principle to the rows corresponding to the sectors S_5, S_6 and S_7.

$$\begin{cases} a_{51}X_1 + a_{52}X_2 + a_{53}X_3 + a_{54}X_4 + a_{57}X_7 + Y_5 = X_5 \\ a_{61}X_1 + a_{62}X_2 + a_{63}X_3 + a_{64}X_4 + a_{67}X_7 + Y_6 = X_6 \\ a_{71}X_1 + a_{72}X_2 + a_{73}X_3 + a_{74}X_4 + a_{77}X_7 + Y_7 = X_7 \end{cases} \tag{C7}$$

Substituting (C1), (C2), (C5) and (C6) in (C7),

$$\begin{cases} (a_{51}\alpha + a_{52}\beta)X_5 + (a_{53}\gamma + a_{54}\delta)X_6 + a_{57}X_7 + Y_5 = X_5 \\ (a_{61}\alpha + a_{62}\beta)X_5 + (a_{63}\gamma + a_{64}\delta)X_6 + a_{67}X_7 + Y_6 = X_6 \\ (a_{71}\alpha + a_{72}\beta)X_5 + (a_{73}\gamma + a_{74}\delta)X_6 + a_{77}X_7 + Y_7 = X_7 \end{cases} \tag{C8}$$

Typically in an IO model Y_5, Y_6 and Y_7 are exogenous variables and X_5, X_6 and X_7 are endogenous variables. The equation's system of (C8) is similar to the conditions of the basic IO model (Eq. (3′))

$$AX + Y = X \tag{3'}$$

where $A = \begin{Bmatrix} (a_{51}\alpha + a_{52}\beta) & (a_{53}\gamma + a_{54}\delta) & a_{57} \\ (a_{61}\alpha + a_{62}\beta) & (a_{63}\gamma + a_{64}\delta) & a_{67} \\ (a_{71}\alpha + a_{72}\beta) & (a_{73}\gamma + a_{74}\delta) & a_{77} \end{Bmatrix}$, $X = \begin{Bmatrix} X_5 \\ X_6 \\ X_7 \end{Bmatrix}$, $Y = \begin{Bmatrix} Y_5 \\ Y_6 \\ Y_7 \end{Bmatrix}$

The solution of the extended IO model is found in the same way as the basic IO model, (Eq. (C4))

C2. Example commodity-based and industry-based approach

Assumed is that sugar and ethanol are produced in a given economy by the following technologies:

T_1: Technology that produces ethanol and sugar simultaneously (mix sugarmill);

Table D12
Contribution of the different cost items to repair and maintenance costs.

Items R&M	In planting, chemical application and harvesting (%)	In transport equipment (%)	In irrigation equipment (%)	R&M of facilities (%)	Data source
Resine, plastic and rubber products	39	–	30	28	([67], expert field work)
Steel and metal products	53	30	15	40	([67], expert field work)
Electrical machines and equipment	3	8	53	30	([67], expert field work)
Accessories for vehicles	3	60	–	–	([67], expert field work)
Hired R&M services	2	2	2	2	([67], expert field work)

T_2: Technology that produces only-ethanol (distillery);

In the first technology, the *commodity-based approach* is applied (Table C1), one part of the production of this sector is directed to the production of ethanol ($\beta_{1,3}$) and the other part will be directed to the production of sugar ($\beta_{1,4}$). The total output (X_1) of technology 1 (T_1) will be given by

$$X_1 = \beta_{1,3} + \beta_{1,4} \quad \text{(C9)}$$

where $\beta_{1,3}+\beta_{1,4}=1$ and $0<\beta_{1,3}, \beta_{1,4}<1$

The industry-based approach is applied for the total amount of ethanol produced (X_3) that will come from the ethanol produced in a mix sugarmill ($\beta_{1,4}\, X_1$) and that generated in a distillery ($\alpha_{2,3}\, X_2$) as explained earlier.

When considering all the agricultural and industrial technologies that can take place in the scenarios studied a total number of 15 new technologies are obtained. These technologies are responsible for the production of five different commodities which are sugarcane, ethanol, sugar, electricity and livestock. The technologies can be combined in each scenario. For example, the BaU scenario in 2020 assumes that there will be 50% of mechanical harvested sugarcane and 50% of the manual harvested sugarcane and therefore, according to the technologies presented in Table 5, there will be 50% of the technology "Sc_Man 20" and 50% of the technology "Sc_Mec 20".

C3. Sector aggregation

See Appendix Tables C2.

C4. Simplified structure of the extended inter-regional IO model that is used in this study

See Appendix Table C3.

Appendix D. Input data

The cost data in the study of ESALQ [49] is given for two types of sugarcane production systems (sugarmills and outgrowers). Since the production costs for outgrowers and for sugarmills were not very different, this study has calculated one single production cost for the NE region to simplify the calculations in the extended IO model. From

Table D13
Technical coefficients calculated for the different agricultural and livestock technologies introduced in the extended IO model.

IO sector number	Livestock technologies		Agricultural technologies					
	Lvst (2 heads/ha)	Lvst Tec (3 heads/ha)	Sc_Man 10	Sc_Mec 10	Sc_Man 20	Sc_Mec 20	Sc_ManTec 20	Sc_Mec Tec 20
1	0.048	0.042	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.050	0.050	0.046	0.046	0.043	0.043
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.006	0.005	0.000	0.000	0.000	0.000	0.016	0.016
6	0.053	0.047	0.000	0.000	0.000	0.000	0.000	0.000
7	0.007	0.007	0.000	0.000	0.000	0.000	0.000	0.000
8	0.126	0.168	0.000	0.000	0.000	0.000	0.000	0.000
9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001
11	0.016	0.014	0.105	0.135	0.096	0.123	0.096	0.122
12	0.012	0.011	0.135	0.135	0.124	0.124	0.116	0.116
13	0.001	0.001	0.029	0.038	0.026	0.035	0.033	0.041
14	0.015	0.013	0.000	0.000	0.000	0.000	0.000	0.000
15	0.004	0.003	0.040	0.040	0.036	0.036	0.034	0.034
16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	0.000	0.000	0.017	0.017	0.016	0.016	0.015	0.015
19	0.001	0.001	0.053	0.066	0.049	0.060	0.050	0.061
20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
21	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
22	0.000	0.000	0.014	0.015	0.013	0.013	0.029	0.029
23	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
24	0.000	0.000	0.028	0.029	0.026	0.027	0.028	0.029
25	0.000	0.000	0.017	0.017	0.016	0.016	0.010	0.010
26	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
27	0.035	0.031	0.000	0.000	0.000	0.000	0.000	0.000
28	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
29	0.009	0.008	0.000	0.000	0.000	0.000	0.000	0.000
30	0.003	0.003	0.007	0.007	0.006	0.006	0.006	0.006
31	0.007	0.007	0.028	0.028	0.025	0.025	0.016	0.016
32	0.000	0.000	0.003	0.003	0.002	0.002	0.002	0.002
33	0.000	0.000	0.002	0.003	0.002	0.003	0.003	0.003
34	0.002	0.002	0.000	0.000	0.000	0.000	0.000	0.000
Labour	0.606	0.592	0.284	0.128	0.259	0.117	0.264	0.113
Capital	0.047	0.044	0.185	0.287	0.255	0.349	0.238	0.343

Lvst Tec: Livestock production intensified (3 heads/ha).
Sc_Man 10: Agricultural technology in 2010 with 100% manual harvest.
Sc_Mec 10: Agricultural technology in 2010 with 100% mechanical harvest.
Sc_Man 20: Agricultural technology in 2020 with 100% manual harvest.
Sc_Mec 20: Agricultural technology in 2020 with 100% mechanical harvest.
Sc_ManTec 20: Agricultural technology in 2020 with 100% manual harvest and higher technological levels (e.g., irrigation, better sugarcane varieties).
Sc_MecTec 20: Agricultural technology in 2020 with 100% mechanical harvest and higher technological levels (e.g., irrigation, better sugarcane varieties).

the two production costs, the weighted average was calculated considering that 70% of the total sugarcane of the NE is produced by sugarmills and 30% comes from outgrowers, see Table D1.

It was necessary to further disaggregate the production costs of Table D1 in order to allocate each cost to the corresponding sectors of the initial IO table (e.g., the cost of mechanised operations had to be further divided in fuel cost and repair and maintenance cost). This additional disaggregation of the costs was applied for the mechanised operation costs, the agricultural inputs used and the administration costs by using additional literature and estimates of experts at CTBE [67]. The contribution of each component item to these costs is given in the tables below. The costs of repair and maintenance (R&M) for the mechanised operations were further disaggregated. This was done for all those processes that include mechanised operations (soil preparation and planting, the application of fertilizers and agrochemicals, irrigation, harvesting and the transport of sugarcane) and also for the R&M of facilities (e.g., offices, house for staff, grids for electricity, dams, machine sheds and the water treatment station) which were included in the total administrative costs. In order to translate the costs expenditures of R&M into the different sectors of the IO table, all IO sectors that could potentially contribute to these costs were considered. Table D12 shows the individual contribution of each expense to the total R&M costs of the operations involved during the production of sugarcane, sugar and ethanol.

The cost data related to the harvest of sugarcane is given in Table D2, and data related to the irrigation systems considered in the scenarios A and B in Table D3. The benefits accompanying the use of irrigation were also included in the cost data used. The use of irrigation increases the longevity of the crop which reduces the implementation costs looking over the lifetime of the sugarcane, see Table D4 [68]. On the other hand, higher yields are obtained and thus, as a consequence, other costs will increase (e.g., fertilisation costs, harvest costs, transport costs). Although some of these increases can be considered proportional to the growth in yields, in the case of the use of fertilizers the increase is not necessarily proportional. This is because of the high efficiency in fertilizer's application when using ferti-irrigation systems.

Table D14
Technical coefficients calculated for the different industrial technologies introduced in the extended IO model.

IO sector number	Industrial technologies							
	Et10	Et20	Sug10	Sug20	(Et+Sug)10	(Et+Sug)20	(E+El)20	(Et+Sug+El)20
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.684	0.684	0.666	0.666	0.672	0.672	0.591	0.592
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
11	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13	0.016	0.016	0.027	0.027	0.023	0.023	0.013	0.020
14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	0.018	0.018	0.013	0.013	0.015	0.015	0.016	0.013
17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
19	0.021	0.021	0.021	0.021	0.021	0.021	0.018	0.018
20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
21	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
22	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
23	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
24	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25	0.004	0.004	0.004	0.004	0.004	0.004	0.003	0.003
26	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
27	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
28	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
29	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
30	0.012	0.012	0.012	0.012	0.012	0.012	0.011	0.011
31	0.020	0.020	0.020	0.020	0.020	0.020	0.018	0.018
32	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
33	0.014	0.014	0.014	0.014	0.014	0.014	0.012	0.012
34	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Labour	0.076	0.076	0.073	0.073	0.074	0.074	0.065	0.065
Capital	0.125	0.125	0.142	0.142	0.136	0.136	0.244	0.239

Et10: Technology in 2010 in the distilleries,
Et20: BaU technology in the distilleries in 2020,
Sug10: Technology in 2010 in the sugarmills producing sugar,
Sug20: BaU technology in the sugar factories in 2020,
(Et+Sug)10: Technology in 2010 in the mixed sugarmills,
(Et+Sug)20: BaU technology in the mixed sugarmills in 2020,
(Et+El)20: Technological improvement for distilleries in 2020 (e.g., surplus electricity produced, more efficient equipment),
(Et+Sug+El)20: Technological improvement for mixed sugarmills in 2020 (e.g. surplus electricity produced, more efficient equipment),

Considering all these effects, the modifications introduced in the costs for irrigated areas were estimated.

To include the benefits from the use of improved sugarcane species, it was assumed that the large and medium sugarcane producers (responsible for 35% of total sugarcane produced) help financing the necessary R&D programs to develop new species, which is common practise. Currently R&D programs are partly financed by the private sector and partly by public funds [69]. It was assumed that 1% of the total production costs were earmarked for R&D programs to develop better sugarcane varieties.

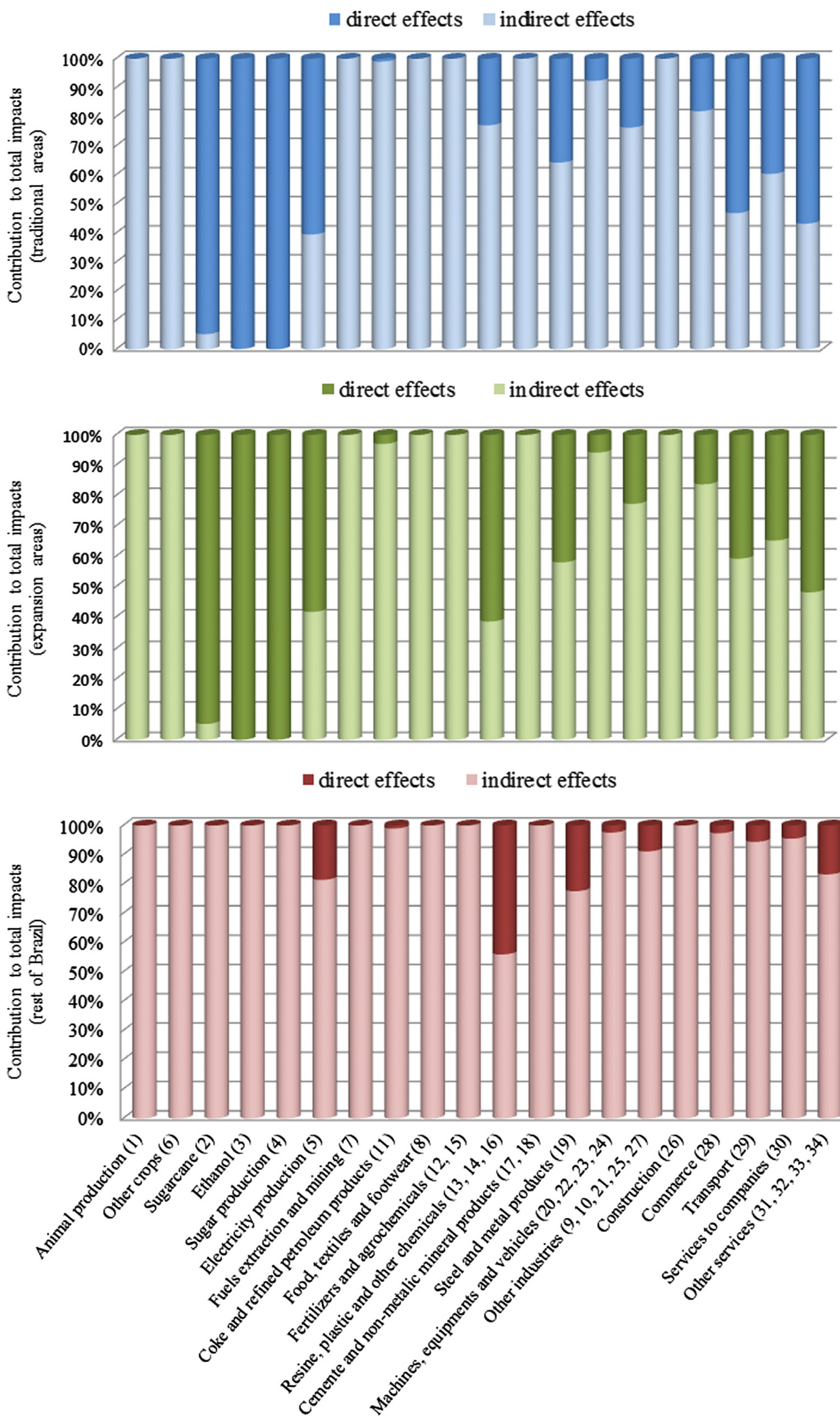


Fig. E1. Contribution of direct and indirect effects on the GDP for all sectors in the traditional and expansion areas of NE Brazil and in the rest of Brazil.

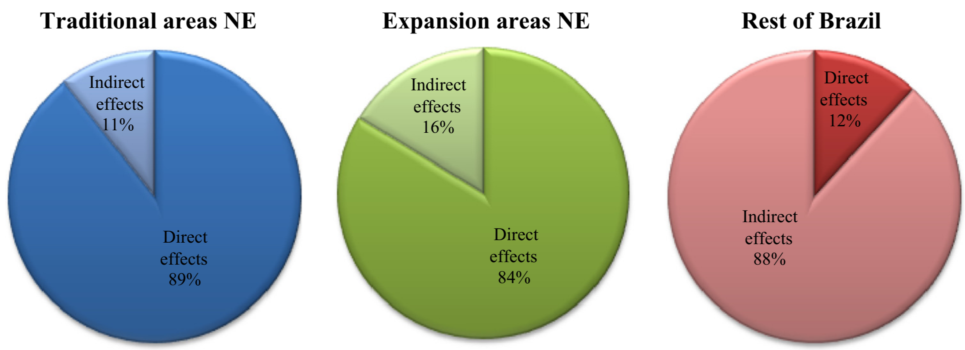


Fig. E2. Contribution of direct and indirect effects to the total impact observed for GDP in the three studied regions in a simulation where the traditional and expansion areas of NE are identical in terms of production.

Table E1
Changes in total output for the three scenarios studied, including the reference scenario.

Sector name (#)[a]	X (million US$_{2010}$)					
	Reference scenario			BaU scenario		
	Trad NE	Exp NE	ROB	Trad NE	Exp NE	ROB
Animal production (1)	0.1	0.2	1.5	0.1	0.2	1.5
Other crops (6)	0.2	1.0	5.1	0.2	1.0	5.4
Sugarcane (2)	1462	345	5	1592	376	4.9
Ethanol (3)	1286	430	9	1408	471	9.8
Sugar production (4)	1407	182	1	1542	200	1.2
Electricity production (5)	3.3	7.3	10.9	3.5	7.9	11.6
Fuels extraction and mining (7)	2.3	19.1	90.9	2.3	20.5	97.6
Coke and refined petroleum products (11)	2.5	44.1	156.8	2.7	47.7	170.1
Food, textiles and footwear (8)	2.2	1.5	8.9	2.3	1.6	9.4
Fertilizers and agrochemicals (12, 15)	11.7	94.3	212.8	11.6	94.6	213.8
Resine, plastic and other chemicals (13, 14, 16)	5.2	18.7	190.0	5.6	20.4	207.4
Cemente and non-metalic mineral products (17, 18)	6.1	2.6	19.7	6.0	2.6	19.7
Steel and metal products (19)	26.2	17.2	145.4	28.6	18.7	157.1
Machines, equipments and vehicles (20, 22, 23, 24)	3.1	5.7	105.2	3.2	5.8	107.7
Other industries (9, 10, 21, 25, 27)	41.8	17.8	69.1	43.1	18.4	72.8
Construction (26)	1.4	0.9	3.1	1.5	1.0	3.3
Commerce (28)	72.7	27.1	48.1	77.4	28.7	50.5
Transport (29)	42.3	18.8	46.6	45.5	20.0	49.4
Services to companies (30)	65.3	25.1	56.7	69.5	26.5	59.9
Other services (31, 32, 33, 34)	162.5	50.4	71.6	172.3	53.1	75.6
Total	4603	1309	1258	5018	1416	1329

Sector name (#)1	X (million US$_{2010}$)					
	Scenario A			Scenario B		
	Trad NE	Exp NE	ROB	Trad NE	Exp NE	ROB
Animal production (1)	0.2	0.3	1.9	0.3	0.8	4.4
Other crops (6)	0.3	1.3	6.9	0.6	4.0	15.6
Ethanol (3)	2188	619	12	2188	6844	30
Sugar production (4)	1591	257	1	1591	264	3
Electricity production (5)	29.3	16.4	19.0	31.1	81.3	40.5
Fuels extraction and mining (7)	2.6	21.8	114.5	5.0	71.0	276.9
Coke and refined petroleum products (11)	3.2	58.6	210.6	3.2	271.7	419.3
Food, textiles and footwear (8)	2.8	2.0	11.6	4.2	7.3	26.9
Fertilizers and agrochemicals (12, 15)	13.6	113.7	257.0	19.1	434.2	466.3
Resine, plastic and other chemicals (13, 14, 16)	7.6	29.6	289.7	15.4	121.2	608.6
Cemente and non-metalic mineral products (17, 18)	7.1	3.0	23.5	13.0	13.9	54.2
Steel and metal products (19)	38.9	25.9	207.3	59.0	147.9	447.3
Machines, equipments and vehicles (20, 22, 23, 24)	5.3	9.1	159.5	10.5	52.6	355.7
Other industries (9, 10, 21, 25, 27)	46.0	21.4	92.2	52.8	118.0	202.7
Construction (26)	1.7	1.2	4.2	1.9	5.8	9.2
Commerce (28)	98.9	37.4	65.6	103.5	251.6	133.7
Transport (29)	59.5	26.6	63.1	63.1	157.3	132.3
Services to companies (30)	79.5	33.1	75.6	83.2	200.3	153.0
Other services (31, 32, 33, 34)	207.5	68.1	94.6	214.3	455.2	180.9
Total	4382	1345	1710	4459	9502	3560

[a] Due to the large amount of data some sectors have been grouped.

Table E2
Impacts of investments on GDP and employment for each scenario.

	Impacts on GDP (million US$$_{2010}$)			Impacts on employment (number of jobs)		
	BaU scenario	A scenario	B scenario	BaU scenario	A scenario	B scenario
Machines and equipments						
Traditional areas NE	0.21	1.03	4.12	14	69	278
Expansion areas NE	0.88	4.26	17.07	39	190	762
Rest of Brazil NE	39	187	749	1239	5999	24,017
Electrical machines and equipment						
Traditional areas NE	0.01	0.38	1.18	1	26	79
Expansion areas NE	0.04	1.15	1.40	2	65	200
Rest of Brazil NE	1.9	58	179	61	1868	5745
Motor vehicles						
Traditional areas NE	0.02	0.07	0.43	1	5	34
Expansion areas NE	0.06	0.22	0.22	4	14	89
Rest of Brazil NE	2.9	11	69	98	369	2344
Construction						
Traditional areas NE	0.02	0.21	0.73	1	15	51
Expansion areas NE	0.04	0.53	1.86	2	28	99
Rest of Brazil NE	3.41	41	144	218	2613	9208
Total impact (all regions)	48	305	1168	1681	11,261	42,906

Table E3
Total investments required to obtain the additional production of sugarcane in the three scenarios in the NE.

Capital items in the investments needed	BaU		A		B	
	Traditional areas NE	Expansion areas NE	Traditional areas NE	Expansion areas NE	Traditional areas NE	Expansion areas NE
Machines and equipments	508	121	2458	585	2458	9725
Electrical equipment	27	6	846	182	1034	2126
Vehicles[a]	24	6	92	22	92	629
Construction	102	23	1215	280	1196	4074
Total investments (million US$$_{2010}$)	661	156	4611	1068	4780	16,553

[a] Includes automobiles, trucks and buses.

Table E4
Average monthly salaries paid to employees in each sector in reference scenario and scenario A.

Sector name (#)	Average wages (US$$_{2010}$/month)					
	Reference scenario			Scenario A		
	Traditional areas NE	Expansion areas NE	Rest of Brazil	Traditional areas NE	Expansion areas NE	Rest of Brazil
Animal production (1)	126	142	308	126	142	308
Other crops (6)	58	135	255	58	308	255
Sugarcane (2)	330	329	362	340	135	362
Ethanol (3)	597	609	786	599	255	786
Sugar production (4)	553	561	663	561	561	663
Electricity production (5)	2972	2735	3622	3067	2823	3622
Fuels extraction and mining (7)	302	1164	1602	302	1164	1602
Coke and refined petroleum products (11)	5577	6550	5920	5577	6550	5920
Food, textiles and footwear (8)	330	283	407	330	283	407
Fertilizers and agrochemicals (12, 15)	1992	1773	2164	1991	1768	2151
Resine, plastic and other chemicals (13, 14, 16)	1665	1242	1123	1722	1231	1122
Cemente and non-metalic mineral products (17, 18)	270	271	525	270	271	525
Steel and metal products (19)	697	905	890	697	905	890
Machines, equipments and vehicles (20, 22, 23, 24)	1325	1262	1359	1355	1282	1356
Other industries (9, 10, 21, 25, 27)	762	857	883	757	859	882
Construction (26)	185	242	396	185	242	396
Commerce (28)	217	258	406	217	258	406
Transport (29)	333	398	694	333	398	694
Services to companies (30)	410	417	682	410	417	682
Other services (31, 32, 33, 34)	410	484	819	377	451	785
Average salary	441	467	793	445	473	792

The total sugarcane production costs are assumed to remain unchanged over time and thus, the cost of 40 $US\$_{2010}$/t (Table D1) will be the same for all scenarios. It is assumed that although the productivity gains reduce the production costs, the price difference, or profits, will be re-invested in capital.

Taking the costs of the livestock sector in 2010 as a reference, two assumptions are made to include a semi-intensification of the livestock in the extended IO model (i) animal feed will increase proportionally to the intensification that takes place, leading to 50% increased costs for the semi-intensified system and (ii) labour costs will increase with 10% compared with the reference livestock technology.

The same procedure that is used to calculate the technical coefficients for the agricultural production system, has been applied for the industrial technologies. Based on a series of parameters that define a typical sugarmill in the NE region (see Table D5), ESALQ [49,58] has calculated the industrial production costs (see Table D6). The production costs per ton sugarcane were used for a sugarmill producing both sugar and ethanol while the production costs per tonne of sugar and ethanol were used for factories producing only sugar and producing only ethanol respectively.

Since scenarios A and B include technologies that use more efficient industrial equipment and that are capable to generate surplus electricity, additional information is needed which is provided in Tables D7 and D8.

Table D9 shows the data that was used to calculate the average salaries paid to employees in the studied scenarios. A large difference in labour costs between the scenarios occurs due to the change from manual harvesting to mechanised harvesting. The use of irrigation (and the consequent need of more specialized labour) is assumed not to change the total labour costs from the reference case significantly. It is assumed that employers have to pay 27% of the wage on additional expenditures to pay the social security funds of the employees.

D.1. Allocation of the input data to the IO sectors in the model

The different technical coefficients of the different items involved in the sugarcane–ethanol–sugar production were allocated into the corresponding sector of the extended IO model. Tables D10–D14 illustrates the assignment of the production cost items to the IO sectors in which they are produced. In the IBGE database [71] a detailed specification is given of all the items contained in the IO sector which facilitates the allocation of the different cost items to the IO sectors.

Appendix E. Detailed output results

Results are only presented for value added and for the BaU scenario because all other scenarios lead to similar results. In order to facilitate the presentation of the results in the figure some sectors have been aggregated (Figs. E1 and E2).

Please see appendix Tables E1–E4

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